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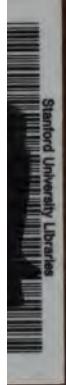
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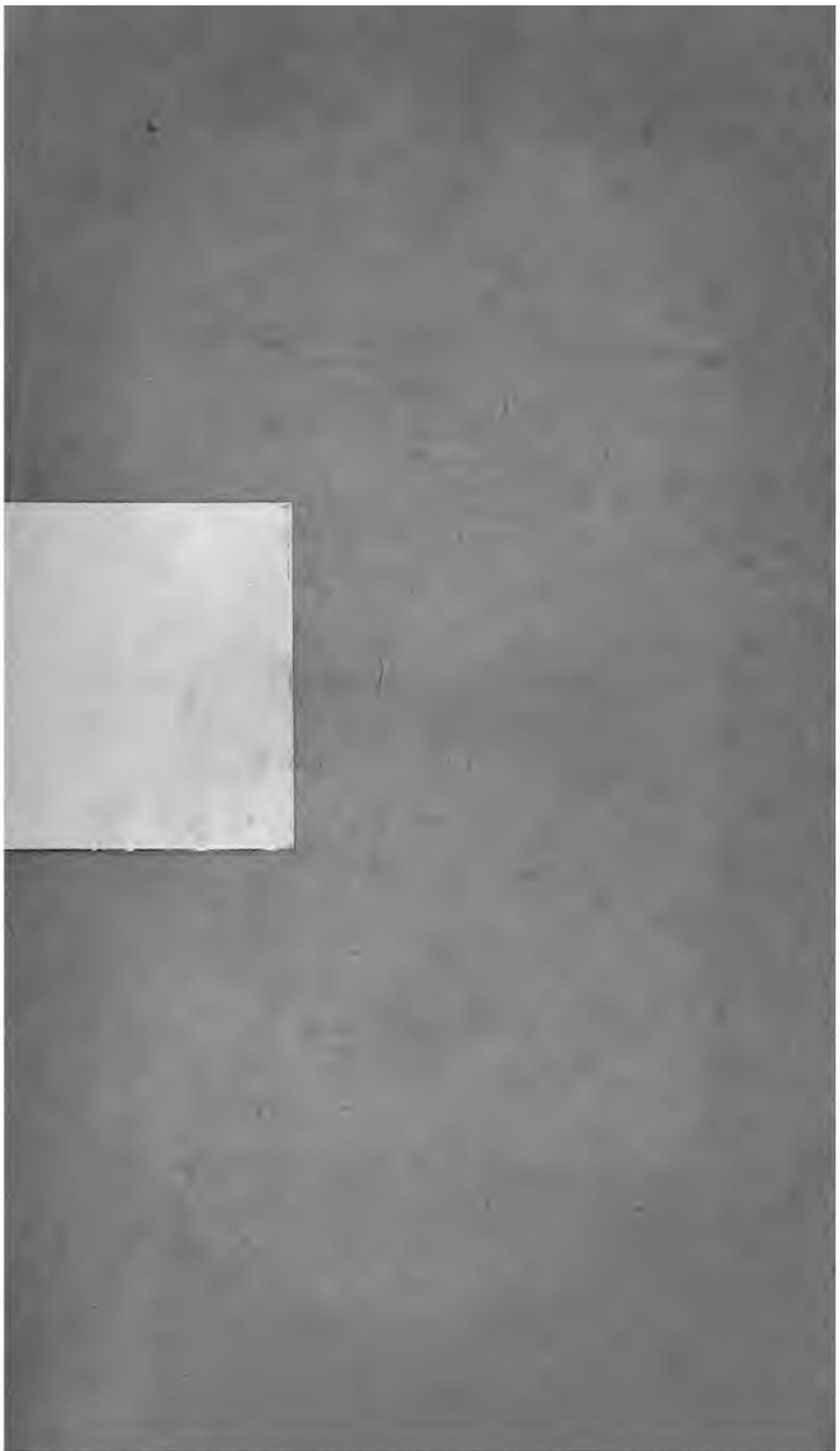


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BULLETIN 338

THE IRON ORES
OF THE
IRON SPRINGS DISTRICT
SOUTHERN UTAH

BY

C. K. LEITH AND E. C. HARDER



WASHINGTON
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VIA RAIU GRONWALD

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OUTLINE OF PRINCIPAL RESULTS.

In the Iron Springs district of southern Utah, described in this paper, sediments of Carboniferous, Cretaceous, and Tertiary ages have been intruded by large masses of andesite taken to be laccoliths. Erosion following the intrusion developed mountains out of the laccoliths, with surrounding rings of outward-dipping sediments on the lower slopes. Later extrusion of lavas covered the eroded laccoliths and sediments. Subsequent erosion has reexhumed the laccoliths and part of the sediments, leaving the lavas in a surrounding zone. The lower slopes and flats adjacent to the laccoliths are covered by the usual unconsolidated deposits of the Great Basin country. Faulting, principally of the tension type, is prevalent.

The iron ores constitute (1) fissure veins in the andesite, (2) fissure and replacement deposits along the contact of the andesite with the Carboniferous limestone, and (3) breccia cement in the Cretaceous quartzite. The larger deposits are the ones along the limestone-andesite contact. Their longer diameters in general follow the contact with rough lens shape, but there are many irregularities due to faulting and other causes.

About 1,600 exploration pits have been sunk, but the deepest goes down only 130 feet, and has not reached water level. The vertical dimensions of the deposits are therefore unknown. Their total area is 5,430,000 square feet, and their total tonnage, so far as can be measured by area and pits, is about 40,000,000 tons. Probably this estimate is much too small, for the pits do not go to the bottom of the deposits.

The ore is magnetite and hematite, containing a small amount of limonite. Much of it runs above 60 per cent in iron, but the average is about 56 per cent. Phosphorus is uniformly high. Sulphur, copper, and titanium are not present in prohibitive amounts. There is no evidence of increase in sulphur with depth, but water level has not been reached by the pits. The texture is hard and crystalline at the surface; beneath the surface the ores are relatively soft. The gangue is principally quartz or chalcedony near the surface; with depth calcite increases. Garnet, diopside, apatite, mica, hornblende, and other silicates constitute minor constituents of the ore.

The ores are closely related in origin to the intrusion of the andesite laccoliths. The first effect of the intrusion was the contact metamorphism of the adjacent limestone, produced principally by driving out its lime and magnesia carbonates and recrystallizing the remaining constituents, but also by the introduction of silica, iron, and soda. The net result was diminution of volume. Limestone was actually fused, for residues of glass still remain. The net density of the contact minerals is somewhat higher than the density of the unaltered limestone, but the density of the rock as a whole is less than that of the fresh limestone, owing to the content of glass and the pore space. It is suggested that the fusion of the limestone contact phase denied access to the andesite solutions, thus explaining the lack of abundant introduction of minerals from the intrusives along the contact. Had the temperature not reached the fusion point of the limestone (probably about 1,000° C.), other conditions remaining unchanged, the contact phase of the limestone might have been left porous, affording openings for the entrance of the solutions.

The ore-bearing solutions followed shortly after the contact metamorphism of the limestone, and after the outer part, at least, of the andesite laccoliths had crystallized, as shown by the occurrence of ore in fissures in the andesite and limestone contact phase. The ore-bearing solutions carried silicates similar to those previously formed in the limestone contact. The conspicuous feature was the introduction of soda by the ore-bearing solutions into both limestone and andesite along the contact. A comparison of the alteration of the andesite next to the ore with its alteration by weathering brings out clearly the effect of the ore-bearing solutions.

A graphic method of comparison of the fresh and altered rocks brings out various possibilities in the interpretation of analyses.

A consideration of the temperatures of crystallization of some of the silicates deposited with the ores and possible pressures resisting the solutions seems to indicate a probability that the solutions may have been vapors and that they were pneumatolytic after-effects of the andesite intrusions.

It is suggested that the iron was carried as ferrous chloride, which became oxidized at a temperature above 500° C. by breaking up associated water and simultaneously developing free hydrogen. Precipitation came about partly by the neutralization of the acid when it came into contact with the limestone, and partly by the evaporation of the acid with the water which would accompany the diminution of temperature and pressure as the solutions left the andesite. The conspicuous introduction of soda into wall rocks suggests further that the same solution carried salt. This would be decomposed by silicic acid and the soda be deposited as sodium silicate, largely albite, the form in which it is now found.

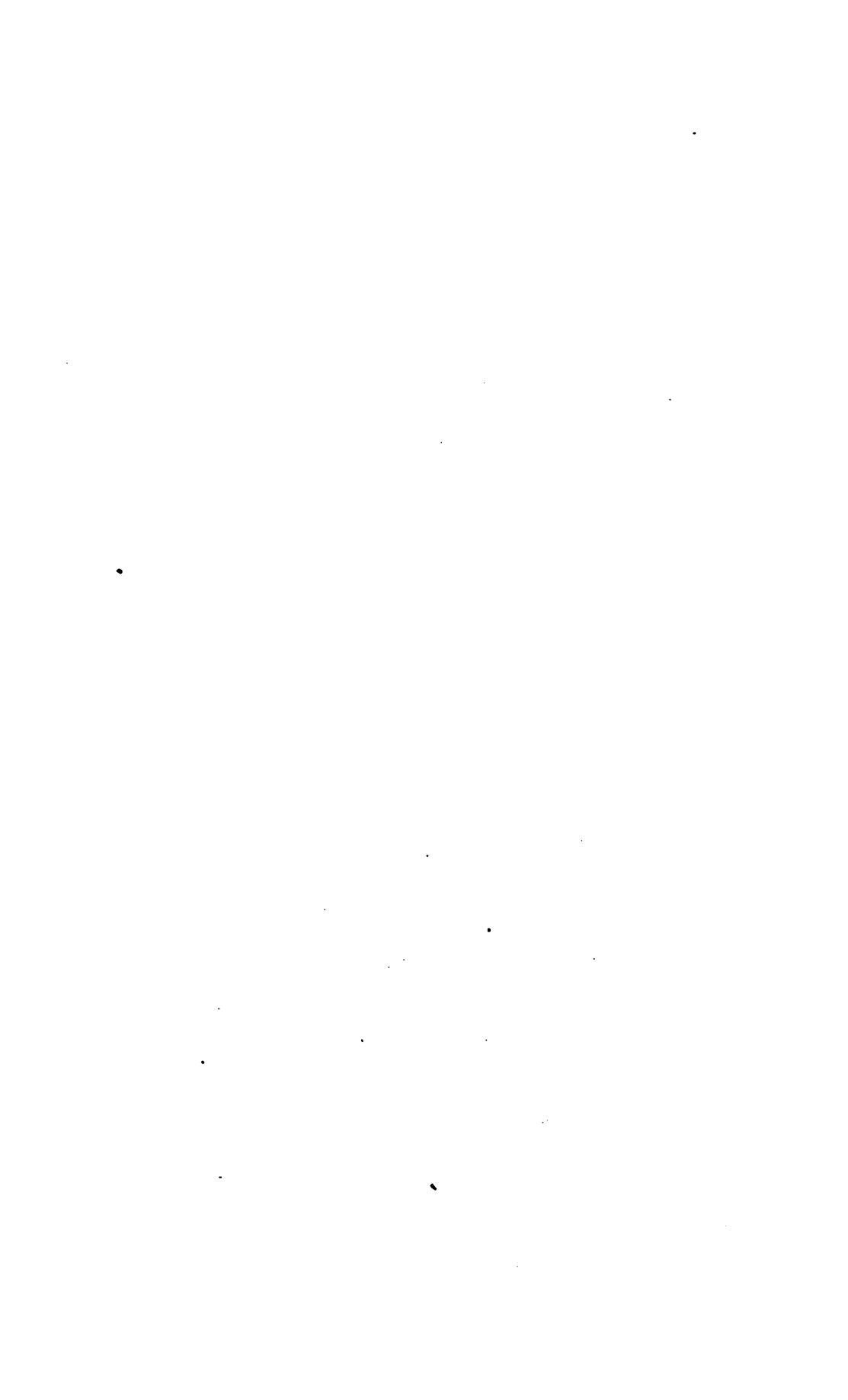
The ore-filled fissures in the andesite and limestone resulted from the cooling of the andesite mass, which developed stretch fractures within the mass and pulled it away from the limestone wall as a casting away from the mold. Where the ore-bearing solutions reached the unaltered limestone rather than the silicated contact phase of the limestone the ore replaced the limestone. Where they reached the overlying quartzite they filled fractures.

A considerable secondary concentration may be traced to the Tertiary lavas which once covered the ore deposits. The ores were coarsely recrystallized and chalcedony was introduced as a gangue material in place of calcite. No heavy silicates were introduced. The concentration under the influence of the lavas is a relatively shallow one, which can be fairly separated from the deep primary concentration.

The entire effect of weathering is not known, because the ores have been observed only above water level. Above this they are porous, suggesting that there may have been a considerable amount of solution of the gangue materials down to this point. Calcite has obviously been leached near the surface and deposited farther down; apatite has been altered to osteolite; small amounts of sulphides have been oxidized and partly removed; limonite has developed in thin films along the margins of cavities and along fissures. In general, however, the obvious relations of the characteristics of the ore to conditions other than weathering seem to indicate that the iron oxides themselves have been little affected by weathering.

Inferences as to the extension and shape of the ore deposits in depth are drawn from a consideration of origin. The ores may have a considerable depth. The ores are not likely to be so thick along the contact on upper slopes, because gravity tended to close the openings formed by the cooling of the andesite mass. There seems to be no reason why ore should not be found at the limestone-andesite contact at places where the contact is now overlain by Cretaceous quartzite.

The Iron Springs deposits are typical of many other western iron-ore deposits, and it is believed from personal observation that their origin has essential features in common. Description is made of the structure of ore of similar occurrence in the adjoining Bull Valley district, and reference is made to deposits regarded as belonging to the same class in other parts of the West.



THE IRON ORES OF THE IRON SPRINGS DISTRICT OF SOUTHERN UTAH.

By CHARLES KENNETH LEITH and EDMUND CECIL HARDER.

CHAPTER I.

INTRODUCTION.

PURPOSE OF THE INVESTIGATION.

The enormous and rapidly increasing consumption of iron ore in the United States during the last few years has led to careful inventories of available supplies, both in producing districts and in relatively unknown fields, with the result in general of emphasizing the limitation of the deposits now worked and of pointing out the necessity for the early exploitation of new ones. Up to the present time less than 2 per cent of the iron ore mined annually has come from west of Mississippi River, but there have long been known in that region large deposits of iron ore which have not been exploited because of lack of transportation facilities or distance from consuming centers. The part these deposits are to play in meeting the future demand for iron ore, the possibilities or probabilities of finding other large deposits in the West, and the geological features of significance in connection with these questions remain largely to be ascertained.

Mr. Leith began a general geological reconnaissance of western iron ores in 1903 and continued it during 1904, 1905, and 1906, visiting some of the better known ore deposits of Utah, Colorado, Wyoming, Washington, British Columbia, California, and Missouri. It early became apparent to him, as it had been apparent to others, that the iron-ore deposits of the West are prevailingly of a distinct and uniform type—an irregular replacement of limestone near the contact with igneous rocks, or a vein filling in both limestone and igneous rock—a type fundamentally different from that of the important producing districts east of Mississippi River, and probably of different origin. The deposits of the Iron Springs district of southern Utah were selected as typical of this class of deposits, well located for study, and of such size and quality as to warrant the belief that their exploitation

would follow in a short time; accordingly, detailed geological work was begun in this district in 1905 by Mr. Leith, with E. C. Harder and Frank J. Katz as field assistants, and was continued during the early part of the field season of 1906 by E. C. Harder and Freeman Ward, the senior author being with the party for three weeks. The results of this work are presented in the following pages. It is believed that they will be found to apply in their essential features to many other deposits of the same general class in western United States.

PREVIOUS WORK.

Lying near the northwest side of the High Plateau region and in the southeast part of the Basin Range province, the Iron Springs district has received passing attention from Powell (1875 and 1879),^a and Dutton (1880 and 1882)^b and associates in their general surveys of the High Plateaus and Colorado River, and from the geologists of the Wheeler Survey—Howell (1875),^c Gilbert (1875),^d and Marvine (1875).^e Their maps and descriptions are necessarily so generalized that they are of little value in detailed study of the district under discussion. They are important, however, in establishing a basis for the general correlation of formations.

The Powell Survey prepared a reconnaissance topographic map of southern Utah, part of which, covering the Iron Springs district, is included in the St. George sheet of the United States Geological Survey. While this is too much generalized to be of use in detailed mapping, it expresses the general topographic and geographic relations of the Iron Springs district to the surrounding territory.

Howell (1875)^f was the first of the early geologists to make anything like a specific description of the Iron Springs district and its iron-ore deposits. He includes analyses of the ores by C. E. Dutton.

In 1880 the deposits received attention from J. S. Newberry,^g then America's leading authority on iron ore. He describes the deposits as constituting "perhaps the most remarkable deposit of iron ore yet developed on this continent," and refers the sediments of the district

^a Powell, J. W., *Exploration of the Colorado River of the West and its tributaries; explored in 1869, 1870, 1871, and 1872, under the direction of the Secretary of the Interior; U. S. Geog. and Geol. Surv. Rocky Mountain Region, Washington, 1875, 291 pp.; Report on the lands of the arid region of the United States, with a more detailed account of the lands of Utah; U. S. Geog. and Geol. Surv. Rocky Mountain Region (2d ed.), 1879, 195 pp.*

^b Dutton, C. E., *Report on the geology of the High Plateaus of Utah; U. S. Geog. and Geol. Surv. Rocky Mt. Region, 1880, 307 pp.; Tertiary history of the Grand Canyon district; Mon. U. S. Geol. Survey, vol. 2, 1882, 264 pp.*

^c Howell, E. E., *Report on the geology of portions of Utah, Nevada, Arizona, and New Mexico, examined in the years 1872 and 1873; U. S. Geog. Surv. W. 100th Mer., vol. 3, Geology, 1875, pt. 3, pp. 227-301.*

^d Gilbert, G. K., *Report on the geology of portions of Nevada, Utah, California, and Arizona examined in the years 1871 and 1872; U. S. Geog. Surv. W. 100th Mer., vol. 3, Geology, pt. 1, 1875, pp. 17-187.*

^e Marvine, A. R., *Report on the geology of route from St. George, Utah, to Gila River, Arizona, examined in 1871; U. S. Geog. Surv. W. 100th Mer., vol. 3 Geology, pt. 2, 1875, pp. 189-225.*

^f Op. cit., pp. 261-263.

^g Newberry, J. S., *The genesis of the ores of iron: School of Mines Quart., Nov., 1880, pp. 9-12.*

doubtfully to the Lower Silurian. Both the ores and the andesite (called granite) he regarded as metamorphosed sediments.

The Iron Springs deposits figure in the Tenth Census report (1886),^a where they were mapped and described by Putnam from an economic standpoint. He referred to them as "probably the largest mass of iron ore in the whole West."

The district lies close to the southeastern shore of Lake Bonneville, and accordingly it appears on the maps accompanying Gilbert's Bonneville report (1890).^b

The physiographic record of the region to the east and south of the Iron Springs district was the subject of careful study in 1904 by Huntington and Goldthwait^c under the direction of W. M. Davis.

The senior author^d of the present report has published two short statements of the results of his examination of the district (1903 and 1906).

A general economic account of the district with special reference to the chemistry of the ores was made by Fred Lerch (1904).^e

A considerable amount of exploration of the district has been done in recent years for commercial interests, the results of which have not been published, but which are incorporated in the present report.

ACKNOWLEDGMENTS.

The authors are indebted to Mr. Fred Lerch, of Biwabik, Minn., to the late Col. S. B. Milner, and to Mr. Archibald Milner, of Salt Lake City, Utah, for many chemical analyses, blueprints of claims, and much general information concerning the district, and to Mr. R. N. Dickman, of Chicago, for chemical analyses. With a single exception, calls for information from the property holders were met fully and promptly. The authors record here their appreciation of the many courtesies afforded them by the people of Cedar City and adjacent territory, which contributed not a little to the comfort and effectiveness of the field work.

^a Putnam, B. T., Notes on the samples of iron ore collected west of the one hundredth meridian: Tenth Census U. S., vol. 15, Mining Industries, 1886, pp. 469-505.

^b Gilbert, G. K., Lake Bonneville: Mon. U. S. Geol. Survey, vol. 1, 1890, pp. 438.

^c Huntington, Ellsworth, and Goldthwait, J. W., The Hurricane fault in the Toquerville district, Utah: Bull. Mus. Comp. Zool., Harvard Coll., No. 42 (Geol. ser., vol. 6), 1904, pp. 199-259.

^d Leith, C. K., Iron ores in southern Utah: Bull. U. S. Geol. Survey No. 225, 1904, pp. 229-237; Iron ores of the western United States and British Columbia: Bull. U. S. Geol. Survey No. 285, 1906, pp. 194-200.

^e Lerch, Fred, The iron-ore deposits in southern Utah: Iron Trade Review, May 19, 1904, pp. 49-50.

CHAPTER II.

GEOGRAPHY, TOPOGRAPHY, AND GENERAL GEOLOGY.

GEOGRAPHY AND TOPOGRAPHY.

The Iron Springs district lies between longitudes $113^{\circ} 10'$ and $113^{\circ} 26' 30''$ and latitudes $37^{\circ} 35'$ and $37^{\circ} 47' 30''$, in Iron County, southern Utah, about 250 miles south of Salt Lake City and 550 miles from the harbor of San Pedro, Cal., on the Pacific Ocean. The San Pedro, Los Angeles and Salt Lake Railroad runs within 22 miles of the district on the west, Lund being the nearest station. The district can also be reached by way of a spur of the Denver and Rio Grande Railroad running down to Marysvale, 80 miles northeast of the district, thence on by stage.

The area (see fig. 1) lies near the eastern margin of the Basin Range province and includes several basin ranges and hills, principal among which are the Harmony Mountains, Iron Mountain, Antelope Range, Granite Mountain, The Three Peaks, and Swett Hills (Pl. I, pocket). To the south are the Pine Valley Mountains. Immediately west, north, and east of the district lies the desert, beyond which on the west and north are other basin ranges, and on the east, 12 miles away, is the Hurricane fault scarp of the High Plateaus. On the southwest the district is continuous with a series of ranges and hills extending west of the Pine Valley Mountains well into Nevada.

The elevation ranges from 5,300 to 8,000 feet.

The drainage is through small creeks leaving the mountains and hills and soon losing themselves in the desert.

The tops of the Harmony Mountains retain snow until the middle of summer, and consequently have an abundance of vegetation, such as yellow pine, fir, cottonwood, quaking aspen, and mountain mahogany. The tops and slopes of the other mountains are dry and are covered with a growth of scrub cedar and piñon. Shrubs, sagebrush, and several species of cacti are also abundant, but grasses are lacking. The surrounding desert presents the variety of sagebrush, rabbit brush, greasewood, and shad scale characteristic of the desert elsewhere in the Great Basin.

The location of the Iron Springs district affords unusual opportunities for the study of Basin Range structure, the relation of the Basin Ranges to the High Plateaus, and the associated problems. From a scenic standpoint also the district is difficult to surpass, affording a view of the massive Pine Valley Mountains, the desert

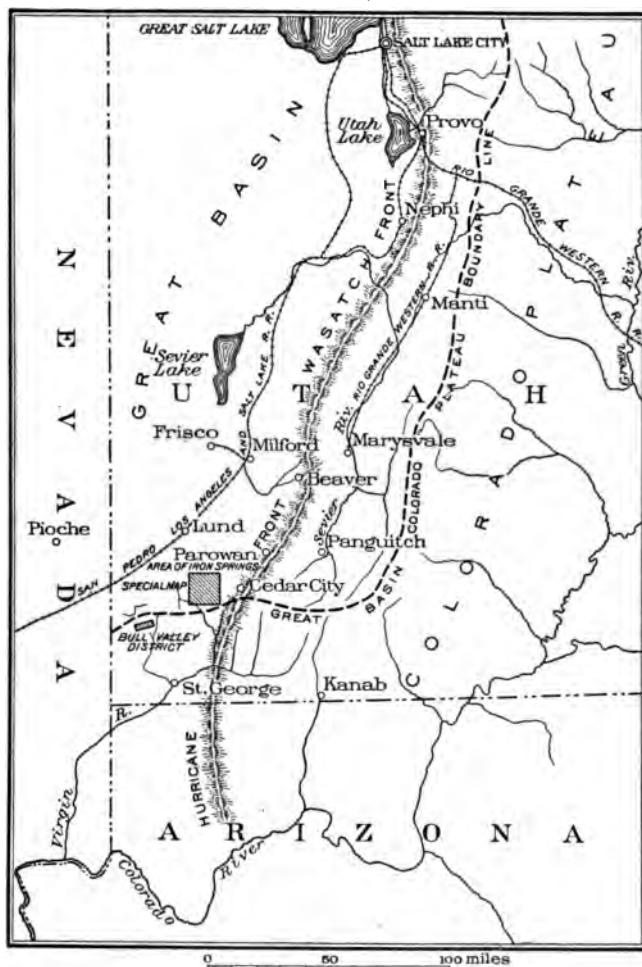


FIG. 1.—Sketch map of parts of Utah, Arizona, and Nevada, showing geographic relation of Iron Springs district to physiographic regions.

in its typical development, and the still more striking, brilliant-colored escarpments of the High Plateaus, notched immediately opposite the Iron Springs district by Cedar Canyon (Coal Creek Valley), which rivals in form and beauty of coloring the canyon of the Virgin, 50 miles to the south, and even the Grand Canyon, 100 miles to the south.

GENERAL GEOLOGY.

The dominating geological features of the district are 3 large andesite laccoliths, constituting The Three Peaks (Pl. VII, *A*), Granite Mountain, and Iron Mountain, lying in a northeast-southwest line across the area mapped. Three unconformable sedimentary series, aggregating 4,000 feet in thickness, outcrop in successive rings around these laccoliths (Pl. VII, *B*), dipping outward asymmetrically, very steeply at the contact, less steeply farther away. Still farther from the laccoliths lava flows 2,000 feet thick rest in nearly horizontal attitude on the tilted sedimentary rocks. These general relations are modified by faulting. All of the rock formations of the district are more or less covered on the middle and lower slopes by unconsolidated and partly consolidated erosion débris, both aqueous and subaerial, which spreads out on the lower ground to make the deserts. The detailed succession is shown in fig. 2.

The laccoliths are exposed only in their upper parts—at no place has erosion shown their bottoms in section. The rock is an andesite of remarkably uniform texture and composition. Within the area of the laccoliths are a few veins of iron ore and fault blocks of ore and Carboniferous and Cretaceous sediments.

In contact with the laccoliths for the most part is Carboniferous limestone, a pure, dense, blue limestone, with a few feet of sandy material appearing locally at the base. The contacts are at most localities nearly vertical, this being due partly to faulting and partly to the fact that erosion has cut down to the sides of the laccoliths, exposing the vertical part of their contact. Locally, where erosion has not gone down so far, the limestone dips distinctly away from the andesite at an angle as low as 10°. The limestone is altered at the contact with the laccolith for a maximum of 1,000 feet, as measured on the erosion slopes, by loss of carbonates, development of anhydrous silicates, and replacement by ore.

Cretaceous sediments outcrop in a zone outside of the Carboniferous limestone, except where locally they are faulted down against the laccolith, or where the laccolith has penetrated the Cretaceous and erosion has not yet cut down to the Carboniferous limestone, as on the west side of Iron Mountain. The Cretaceous rocks are principally sandstone, with layers or lenses of shale, conglomerate, and limestone breccia. At the contact with the laccoliths the sandstone has been indurated and amphibole has developed.

The relations of the Cretaceous sandstone to the underlying Carboniferous limestone are those of apparent conformity, but the contact is rendered somewhat obscure by the presence of shale at the base of the Cretaceous sandstone. The lower portion may be in part Jurassic, but separation could not be made. The greatly varying



A. IRON SPRINGS VALLEY AND THE THREE PEAKS, FROM LINDSAY HILL.



B. CRETACEOUS SEDIMENTS DIPPING AWAY FROM THE ANDESITE ON SOUTHWEST CORNER OF THE THREE PEAKS LACCOLITH.

thickness of the Carboniferous limestone may be due partly to erosion and partly to intrusion of andesite at different horizons. If it represents erosion, this is evidence of unconformity. Notwithstanding the conformity of structure, it is not unlikely that there may be a hiatus between the two systems, for the correlation of

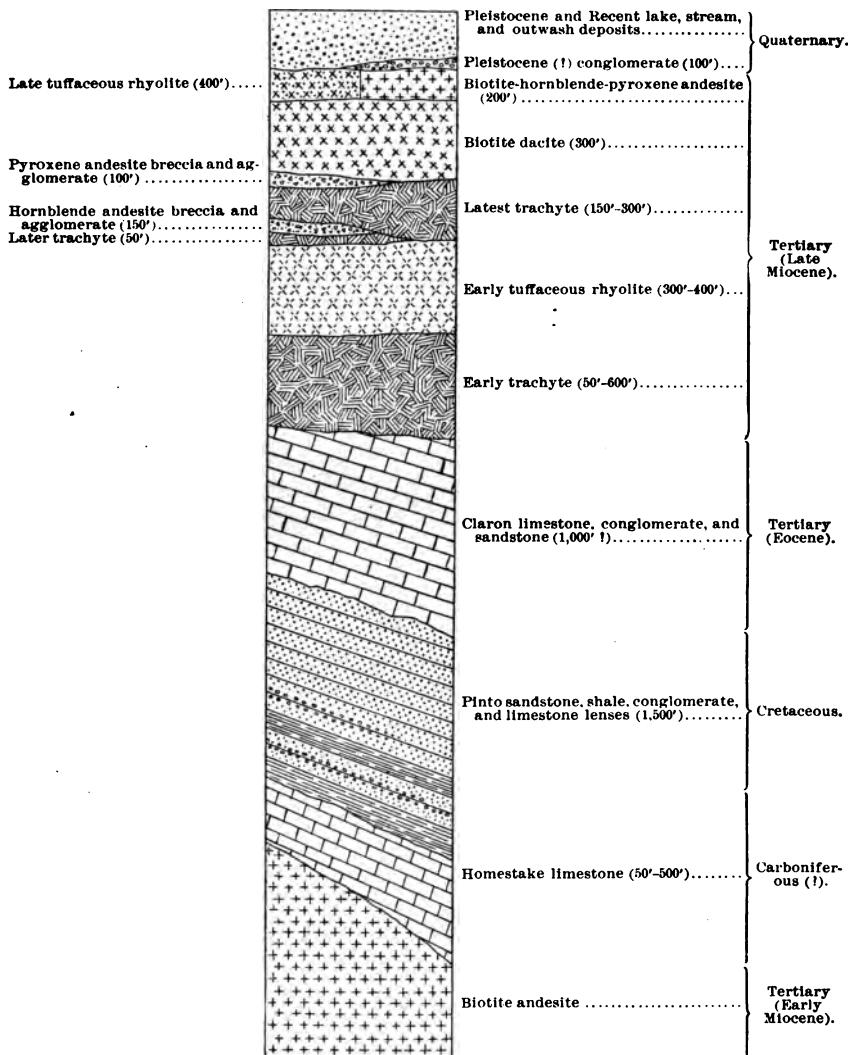


FIG. 2.—Geologic column of the Iron Springs district.

the two is fairly well based, and the Permian, Triassic, and some Jurassic sediments are lacking between them.

The Eocene series outcrops in a zone still farther away from the laccoliths. It consists of limestone and conglomerate, characterized

principally by pink and bright-red colors. A basal conglomerate separates it from the Cretaceous sediments below. The dip of the Cretaceous averages about the same as that of the Tertiary, but there is a marked erosion unconformity between them.

Miocene lavas and tuffs rest nearly horizontally upon the eroded edge of the Eocene sediments and to a less extent upon the Cretaceous.

In the northwestern part of the area, near Antelope Springs, a Pliocene or Pleistocene fluviatile deposit occupies an embayment in the lavas. It is principally a conglomerate containing fragments of the lavas, of the earlier andesite laccolith, and of the sediments.

Pleistocene and Recent lake, stream, and outwash deposits, consisting of gravels, sands, and clays derived from the erosion of all of the rocks of the district, occupy nearly half of the area and mask the rock formations of the lower ground. As a whole this material is a result of disintegration to a larger extent than of decomposition. It is accumulating with extreme rapidity. The hillsides are covered with it and during heavy rain storms a great mass of débris, including fragments many feet in diameter, creeps down the slopes. The finer material is carried down by the torrents and distributed in broad, low fans on the deficient slopes below. The apparently flat "desert" is made up principally of overlapping fans. An hour's heavy rain brings about a conspicuous modification of alluvial fans or other deposits at these places. The extreme rapidity of erosion and transportation in an arid region has often been described, but the amount of material moved in a few hours can scarcely be realized without direct observation.

FAULTS, JOINTS, AND FISSURES.

That faulting complicates the elementary relations above sketched is apparent from an inspection of the general map (Pl. II, pocket). Fault scarps are common. Streams or canyons follow faults and joints, especially the former, so prevailingly that in the mapping faults were looked for whenever a canyon was encountered. Faults have been mapped only where they could be actually proved to exist by the relations of the rock formations, otherwise they are not shown on the map, even where their absence or their abrupt termination looks structurally improbable. It is certain that many have been missed.

The larger and more conspicuous faults have a prevailing north-south trend, but many have other directions, as summarized in fig. 3. At several localities, especially near the ore deposits, a tendency in the faults to follow about the periphery of the andesite laccoliths is observable.

The fault planes are vertical, or nearly so. The displacements vary from vertical to horizontal—principally the former in the faults

mapped. The maximum vertical displacement known is 2,000 feet; the horizontal displacement is unknown. Hinge faults, the displacement at one end of which is opposite to that at the other, were found locally in the lava area. It is probable that many of the faults with a displacement parallel to the dip of the beds have not been mapped because not detected. Allowing for a considerable unknown horizontal component of displacement, there remains a probable dominance of vertical movement sufficient to indicate that the net result

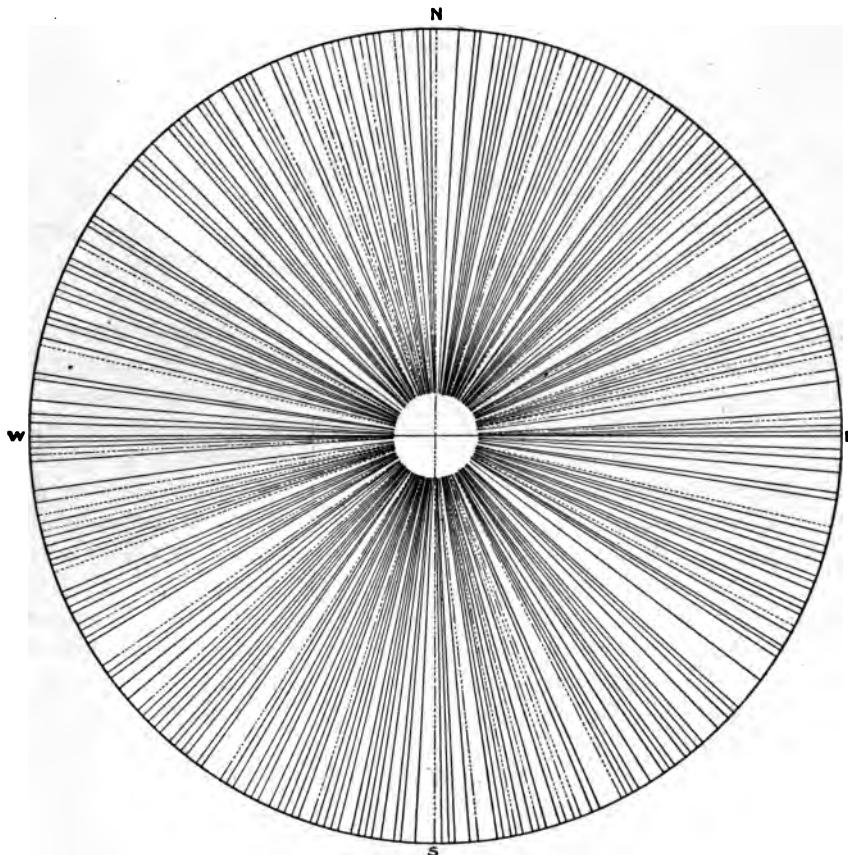


FIG. 3.—Plat of faults and iron-ore veins in the Iron Springs district. Solid lines show faults; dotted lines, iron-ore veins; and solid and dotted lines, faults and iron-ore veins.

of the faulting has been the extension of the area; in other words, the faults are primarily tension phenomena.

Conspicuous in the andesite are fissures, some of them filled with ore, which curve, taper, branch, and parallel themselves in such a manner as to suggest that they are stretch fractures. In the Three Peaks andesite area there is a conspicuous parallel fracturing spaced at intervals of a fraction of an inch to a number of feet. In the neighborhood of ore veins they have the same trend as the veins.

The origin of the faults and other fractures is believed to have been principally due to the successive extension, shortening, and settling accompanying the intrusion and the cooling of the laccoliths—the origin cited by Spurr for some of the faults of the Tonopah district. The faults are tension phenomena, and are so numerous and so intricate in their intersections that it is easier to explain them by somewhat local strains accompanying cooling than by strain on the district as a whole. The faults outlining the periphery of the andesite and the stretch fractures within the andesite may be ascribed definitely to this cause. A rough calculation of the cubic shrinkage of a mass of andesite the size of the Iron Mountain laccolith in crystallizing from a glass to andesite indicates a horizontal radial shortening of between 200 and 500 feet, depending upon the depth assumed for the mass—in any case a large enough factor to be important in the development of fractures.

So far as the faulting was due to the intrusion and cooling of the andesite, it followed the intrusion closely and is of Tertiary age.

Other faults cut the lava flows and are therefore considerably later than the laccolith intrusions. These faults are, from their nature, probably in part due to the cooling of the lavas.

Certain of the larger faults, and especially those having north-south directions, showing great extent and continuity across both igneous and sedimentary formations, may be caused otherwise than by cooling either of laccoliths or of lavas. They seem to belong more to the order of deformation producing the Hurricane fault to the east than to the deformation associated with local igneous action. The whole Iron Springs district represents a downthrow on the west side of the Hurricane fault. The stresses have affected large areas. There can be little doubt that these great faults are essentially tensional in nature, but the cause of the tensional stresses is not clear from the facts available in this area, nor, judging from the literature, from the facts available elsewhere in the Great Basin. King ^a first emphasized the parallelism of faults with folds in the Great Basin region, and Gilbert ^b suggested that the Great Basin faults are but the surface expressions of folds similar to those of the Appalachian Mountains. The parallelism of the faults with axial planes of folds is shown also by the work of Huntington and Goldthwait ^c on the folded and faulted district separating the Great Basin from the high plateaus southeast of the Iron Springs district, where the fault planes and displacements are nearly vertical and the phenomena in general are those of tension.

The correlation of the tensile nature of the strike faults with the shortening of the lithosphere shown by the folds seems possible only

^a King, Clarence, Systematic geology: U. S. Geol. Explor. 40th Par., vol. 1, 1878, p. 735.

^b Gilbert, G. K., Report on the geology of portions of Nevada, Utah, California, and Arizona, examined in the years 1871 and 1872: U. S. Geog. Surv. W. 100th Mer., vol. 3, Geology, pt. 1, 1875, p. 62.

^c Huntington, Ellsworth, and Goldthwait, J. W., The Hurricane fault in the Toquerville district, Utah; *Bull. Mus. Comp. Zool., Harvard Coll.*, No. 42 (Geol. Ser., vol. 6), 1904, pp. 199-259.

by assuming tension along the crests of anticlines, resulting in strike joints and faults. It may be pointed out that no considerable uplift of the arch necessarily precedes faulting of this kind, for the faulting may follow the tendency to uplift so closely that the two movements are nearly simultaneous. It is of interest in this connection to note that Huntington and Goldthwait have developed the fact that the relative vertical movements produced by the folds whose axes are parallel to the Hurricane fault were in opposite directions from those produced by subsequent faults. In the former case the west or Great Basin side was uplifted with reference to the east or High Plateau side, while in the subsequent faulting the Great Basin became the down-throw side, suggesting a drop of the anticline—that is, normal faulting consequent on the folding.

SEQUENCE OF GEOLOGIC EVENTS.

The principal features in the development of the present geological and physiographic features of the district have been in order as follows:

(1) Deposition of Carboniferous limestone, with thin fragmental base, on basement unknown in this district.

(2) A period of nondeposition, perhaps erosion, followed by deposition of Cretaceous and perhaps some Jurassic sandstone with layers of shale, conglomerate, and limestone.

(3) An erosion interval, followed by deposition of Eocene limestone and conglomerate in an inclosed basin. The conditions are principally those of shallow water, strong currents, and rapid changes through both Cretaceous and Tertiary times.

(4) In early Miocene time intrusion of andesite laccoliths, principally into the Carboniferous limestone, but also into the overlying Cretaceous, accompanied by tilting of all the formations away from the laccoliths, steeply near the laccoliths, less steeply farther away. Limestone and sandstone were metamorphosed near the contact.

(5) Fissuring and faulting caused by cooling of laccoliths.

(6) Immediate advent of ore-depositing solutions through fissures in the andesite, depositing iron ore in the andesite fissures and in the adjacent limestone and affecting other alterations.

(7) Erosion, exposing the laccoliths and rings of sediments and ores around them.

(8) Extrusion of late Miocene lavas over the entire area, except possibly some of the higher peaks of the exposed laccoliths, effecting a secondary concentration of the ores and further altering the underlying rocks.

(9) Further faulting.

(10) Vigorous erosion, reexhuming the andesite cores and developing the Pleistocene conglomerate and the Pleistocene and Recent mantle of stream, lake, and other alluvial deposits.

DEVELOPMENT OF TOPOGRAPHY.

The outlines of the andesite cores at their contacts with the sediments are determined largely by their original forms. Their surface forms are in general those of mature topography. While nearly all the surfaces are smooth and rounded, differential erosion along vertical and concentric fissures has developed most irregular and fantastic forms. (See Pl. VIII, *A, B.*)

Erosion of the sediments has developed monoclonal ridges with their steeper edges toward the andesite and dip slopes away from it. Especially conspicuous are the ridges of pink and red conglomerates, sandstones, and limestones of the Eocene, which may be seen for many miles about from points on the laccoliths. In general the relief and slopes of the sediments are low.

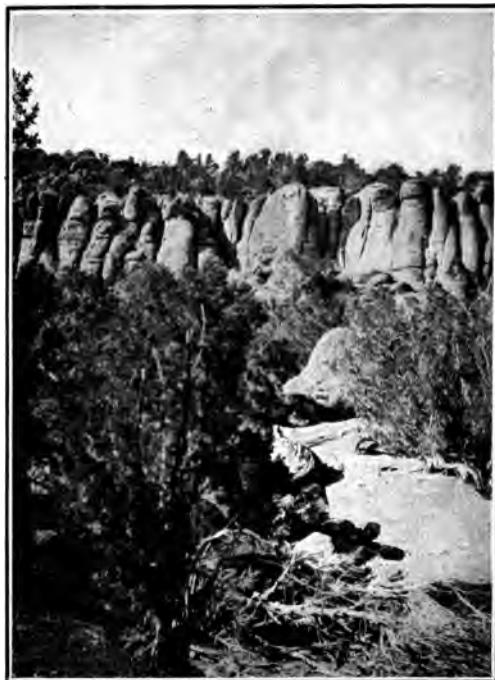
The horizontal lava flows, overlying the sedimentary deposits and fringing the outer edge of the sedimentary area, form conspicuous foothills or mountains, only a little lower than the laccoliths themselves. Erosion has worked down along joints and faults, developing a mesa type of topography, and in detail often presenting the same erosion forms as the laccolithic andesite (Pl. VIII, *C*).

In a broad way the Carboniferous, Cretaceous, and Eocene sediments occupy a valley between mountains formed by the andesite laccoliths and the flat-topped lava hills.

Faults considerably modify the general relations thus outlined. Fault scarps are common, some of them ranging up to 1,000 feet in height, but as a rule erosion has partially or completely masked them. Erosion has frequently worked down along fault planes, with the result that many depressions mark faults. Instances of drainage along fault lines are seen in both branches of the Queatchupah and in several minor valleys to the southeast, in Stoddard Canyon, southeast and northeast of Joel Springs Canyon, around Antelope Range, Antelope Springs, and westward, in the Eightmile Hills, and west of the northern part of The Three Peaks. Instances of canyons following joints were seen abundantly in the western part of The Three Peaks, where there are a number of short parallel canyons following a nearly east-west slicing of the andesite.

The lower slopes in general are grade slopes in the heavy mantle of débris resulting from rapid erosion and inadequate transportation. On the desert this material is spread out in broad, low fans. The grade slopes are notched by sharp ravines and canyons.

The principal events in the development of the present topography have been: (1) Intrusion of laccoliths in early Miocene time, followed by faulting and erosion, exposing the laccoliths and surrounding belts of sediments and developing in the laccolith cores a mature type of topography; (2) extrusion of late Miocene lavas, followed by fault-



A. EROSION FORMS OF THE LATEST TRACHYTE, SWETT HILLS.



B. EROSION FORMS OF LACCOLITHIC ANDESITE THE THREE PEAKS.



C. CONCRETIONARY EROSION OF THE LACCOLITHIC ANDESITE. THE THREE PEAKS.



ing and by erosional exhumation of the laccolith cores and surrounding sediments, so far as these have been covered by the lavas, and developing a mature type of topography in the lavas themselves; (3) Hurricane faulting to the east, causing a slight renewal of activity, exhibited in the sharp canyons and steep sides of some of the lava hills.

There have thus apparently been three partial erosion cycles, the second one now shown chiefly by the flat tops of mesas like the Harmony Mountains and the third by the sharp ravines and canyons. But it is doubtful if the term cycle should be used here, for it implies uplift and renewal of activity of streams, the evidence for which is not satisfactory. There has been an interruption of erosion by the extrusion of the lavas, but the only evidence which can be cited for uplift and renewal are the sharp ravines and canyons; and it may be observed that both these and the grade slopes are being developed at the present time. The rapid development and modification of the grade slopes has already been referred to. But the rapid cutting of the ravines and canyons in these same grade slopes is no less striking. There is an alternate leveling up of the deep ravines to the grade slopes and the development of new ravines in periods of alternating high and low precipitation.

Huntington and Goldthwait, in their excellent paper on the Toquerville area, cut by the Hurricane fault to the southeast of the Iron Springs district, work out two cycles of erosion similar to the second and third here presented. Their first cycle occurred after the extrusion of trachyte, rhyolite, and andesite and subsequent faulting, and corresponds to the second cycle in the Iron Springs district. There appears to be no evidence in the Toquerville district for the prelava and postintrusion cycle of the Iron Springs district. The second cycle of Huntington and Goldthwait occurred after the basalt flows and the later Hurricane faulting. For this cycle there is scant evidence in the Iron Springs district. They cite the Pine Valley Mountains and similar structures of the Iron Springs district and southwest as an expression of the mature topography of their first cycle, and correlate it with certain remnants on the High Plateaus, which were then very much lower than at present, the Pine Valley Mountains being the dominant topographic feature. During the Hurricane faulting the High Plateaus were raised, and renewed erosion cut deep vertical-walled canyons into them, which are the present expression of the second cycle. This faulting produced very little difference of elevation west of the present Hurricane scarp, hence this region, including the Iron Springs district, shows mainly the old mature topography. There are, however, small canyons in the Iron Springs district which may show a renewal of activity and may be comparable to the steep-sided canyons of the High Plateaus.

CHAPTER III.
SEDIMENTARY FORMATIONS.
CARBONIFEROUS SYSTEM.
HOMESTAKE LIMESTONE.

DISTRIBUTION.

The Homestake limestone outcrops in or around the andesite laccolith areas and immediately in contact with the andesite.

West of The Three Peaks laccolith it is exposed in a band extending from the northern boundary of the district southwestward for about 3 miles and then southeastward to a point northeast of Iron Springs, except where, by faulting, the Cretaceous formations are brought into contact with the andesite for a distance of about a mile.

Northeast of the Granite Mountain laccolith a band of Homestake limestone is exposed for about 2 miles. Both ends of this band are overlapped by the Pinto sandstone, which here again comes in contact with the andesite. At the Desert Mound, southwest of Granite Mountain, the Homestake limestone again appears. It is cut off by a fault on the west and disappears under the lake and stream deposits on the east.

The Iron Mountain laccolith is bordered by the Homestake limestone on its northeast, east, south, and southwest sides, with a few interruptions due to faulting or covering by surface deposits. Southwest of the laccolith the limestone has considerable width, owing to the fact that the surface of the supporting laccolith is nearly horizontal here, as shown by the tongue of andesite extending westward from the main mass and by the few andesite outliers in the Homestake limestone. On the west and north sides of the Iron Mountain laccolith, as in Granite Mountain, the Homestake limestone is not exposed, the Cretaceous sandstones lapping against the laccolith.

A patch of Homestake limestone is present in the Comstock iron deposit in the Cretaceous area southwest of the Homestake mine; others are scattered irregularly within the area of the Iron Mountain laccolith.

CHARACTER.

The Homestake limestone is a dark bluish-gray limestone of a dense texture, with uniform characteristics throughout its entire extent, except near the laccolith contact. Under the microscope the limestone appears to be made up of exceedingly minute grains of calcite with scattered grains of pyrite, magnetite, and chert.

The bedding of the Homestake limestone is very indefinite and is easily confused with secondary fracturing. Where it is well defined the limestone is generally thin bedded.

CONTACT METAMORPHISM OF LIMESTONE BY ANDESITE LACCOLITHS.

Phases of alteration.—The limestone adjacent to the andesite has been locally replaced by iron ore and has been generally vitrified, silicified, and kaolinized in a band usually not more than 60 feet wide along the erosion surface, although locally it may be a few hundred yards wide where the erosion surface is nearly parallel to the limestone-andesite contact. Locally either or both contact phases are absent.

The altered limestone is a grayish, yellow, or greenish, fine-grained, argillaceous-looking rock. Near the contact it is soft, and farther away it is hard and fractured into small irregular blocks. The principal minerals are albite, kaolin, actinolite, diopside, quartz, orthoclase, serpentine, phlogopite, andradite, iron ores, osteolite, andalusite, wollastonite, calcite, etc., varying greatly in proportion in different places, but usually occurring in quantity in the order named. They are found in veins, in breccias, and disseminated through the rock. In addition there are local residues of a glassy base. The albite is probably not as abundant as here indicated, but very likely includes other sodium silicates which have not been detected. The glass can be distinguished only with difficulty from opal and other isotropic minerals. Its index of refraction was determined as 1.56 by means of the Becke method used in conjunction with liquids of known index of refraction. This distinguishes it from opal (1.45) and other isotropic minerals which might be found in contact-metamorphic limestones.

Another phase is coarsely crystallized limonite-stained marble, in some places found in a narrow belt between the andesite and the normal silicated contact phase and elsewhere outside of the normal phase or associated with the ore. It is thought possible that this limonitic marble is a later vein material, filling openings along the contact left by the cooling and crystallization of the intrusive and intruded masses.

Analyses of various phases of the Homestake limestone are given on the following pages.

Analyses of Homestake limestone.

UNALTERED HOMESTAKE LIMESTONE.

	A. a	B.	C.	D.	E.	F.	G.
SiO ₂	8.08	6.90	3.78	.....	.....	16.48	3.12
Al ₂ O ₃	1.95	1.03	1.14	.....	.....	1.78	.71
Fe ₂ O ₃.....	.87	1.04	1.80	.....	.....	.....	.....
Fe.....	.....	.....	.....	0.28	0.46	.93	1.12
FeO.....	.06	.75	.....	.....	.....	.....	.....
MgO.....	2.86	4.52	.64	1.78	2.67	.....	.....
CaO.....	46.67	47.15	50.39	50.77	49.46	.....	.....
Na ₂ O.....	.13	.13	.....	.....	.....	.....	.....
K ₂ O.....	.77	.93	.....	.....	.....	.....	.....
H ₂ O +.....	1.01	1.04	.....	.....	.....	.....	.....
P ₂ O ₅.....	.05	.04	.042	.03	.03	.037	.023
CO ₂	37.60	36.42	39.92	.....	.....	.....	.....
BaO.....	None.	None.	.....	.....	.....	.....	.....
	100.05	99.95	97.71	.....	.....	.....	.....

^a These letters are used throughout the discussion of the Homestake limestone in referring to the specimens and their analyses.

ALTERED HOMESTAKE LIMESTONE NEAR ANDESITE CONTACT, AND DIOPSIDE.

	Normal contact phase.			Exceptional contact phases.					Diop-
	H.	I.	J.	K.	L.	M.	N.	O.	side.
SiO ₂	50.73	52.00	57.05	11.31	2.38	4.08	45.03	75.16	51.72
Al ₂ O ₃	14.63	9.32	9.86	1.64	2.02	1.03	1.95	2.39	1.99
Fe ₂ O ₃	11.51	5.08	3.10	4.75	6.20	.....	18.22	.....	3.30
Fe.....	1.13	2.41	1.80	2.55	None.	.....	2.38	.....	4.95
FeO.....	6.36	9.40	8.16	.41	.45	.....	.35	.....	15.08
MgO.....	1.24	14.47	8.61	42.57	48.80	.....	14.99	.....	23.22
CaO.....	2.02	1.94	4.30	.12	.....	.....	1.65	.....	.05
Na ₂ O.....	4.24	1.41	1.56	.25	.....	.....	.72	.....	.06
K ₂ O.....	7.03	3.30	3.89	1.43	2.07	.....	4.09	.....	.50
H ₂ O +.....	.32	.12	.13	2.36	.03	.02	.64	.074	.....
P ₂ O ₅.....	.21	.13	1.74	32.30	.....	.....	9.34	.....	.....
CO ₂.....	.01	None.	None.	.02	None.	.....	.10	.....	.....
MnO.....	.....	.....	.....	.....	.....	.....	.....	.....	.04
	99.43	100.08	100.20	99.71	.....	.....	99.49	.....	100.91

A. Specimen No. 46319. Unaltered blue limestone west of Three Peaks. Analysis by R. D. Hall, University of Wisconsin.

B. Specimen No. 46375. Unaltered blue limestone from Desert Mound. Analysis by R. D. Hall, University of Wisconsin.

C. Unaltered limestone from Iron Mountain. Analysis by Fred Lerch, Biwabik, Minn.

D. Specimen No. 46123. Unaltered blue limestone. Partial analysis by George Steiger, U. S. Geol. Survey.

E. Specimen No. 46121. Unaltered blue limestone. Partial analysis by George Steiger, U. S. Geol. Survey.

F. Specimen No. 46319A. White limestone west of Three Peaks. Analysis by Fred Lerch, Biwabik, Minn.

G. Specimen No. 46325. White limestone west of Three Peaks. Analysis by Fred Lerch, Biwabik Minn.

H. Specimen No. 46338. Altered limestone between ore and andesite on Lindsay Hill. Analysis by R. D. Hall, University of Wisconsin.

I. Specimen No. 46349. Altered limestone between ore and unaltered blue limestone at Desert Mound. Analysis by R. D. Hall, University of Wisconsin.

J. Specimen No. 46376. Altered limestone between ore and andesite at Desert Mound. Analysis by R. D. Hall, University of Wisconsin.

K. Specimen No. 46437. Recrystallized limestone in vein a few feet thick at andesite contact, showing partial replacement by iron and silica. From Boston claim. Analysis by R. D. Hall, University of Wisconsin.

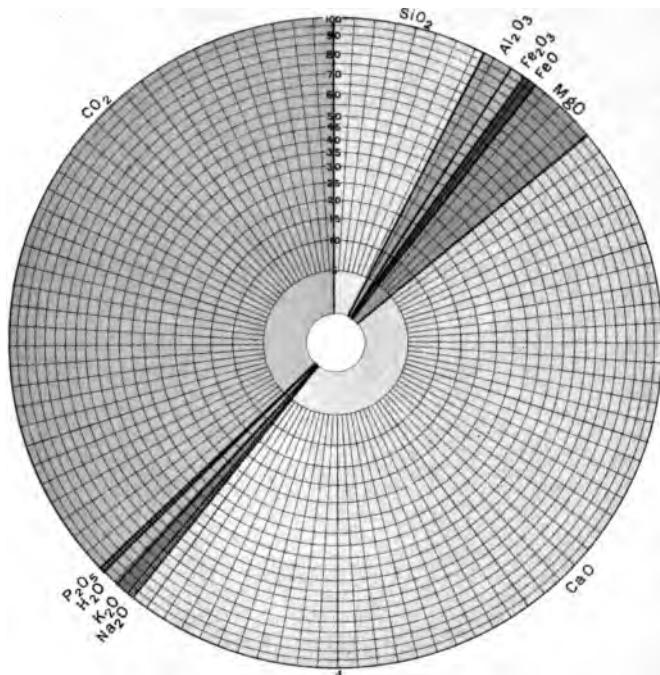
L. Specimen No. 46320. Recrystallized limestone impregnated with limonite, in vein near andesite-limestone contact west of Three Peaks. Analysis by R. D. Hall, University of Wisconsin.

M. Specimen No. 46321. Same as L. Analysis by Fred Lerch, Biwabik, Minn.

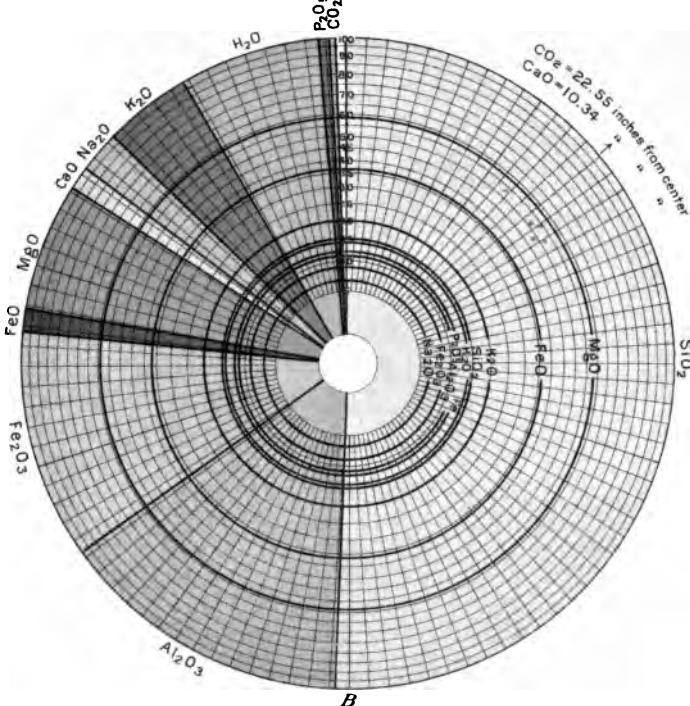
N. Specimen No. 46438. Same as K, showing a further stage in replacement by iron and silica. Analysis by R. D. Hall, University of Wisconsin.

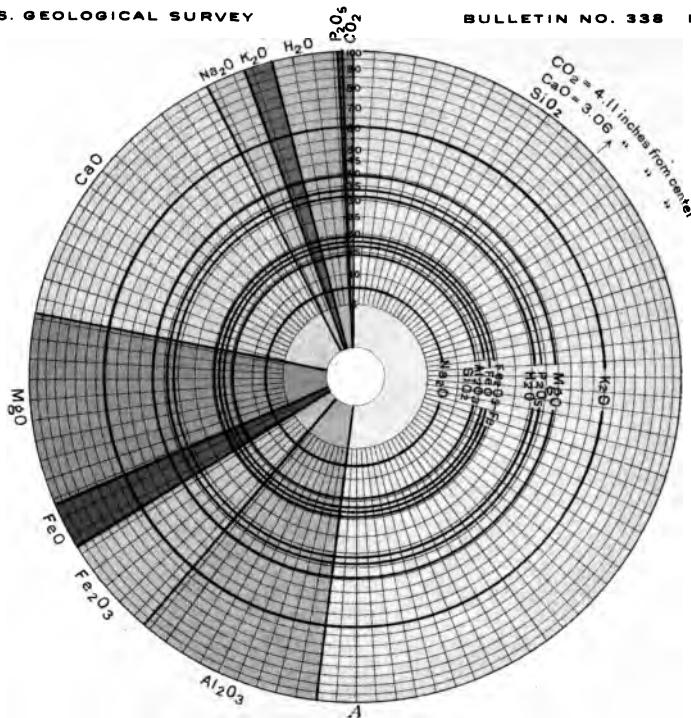
O. Specimen No. 46326. Siliceous platy alteration phase of limestone west of Three Peaks. Analysis by Fred Lerch, Biwabik, Minn.

P. Specimen No. 46478. Diopside from long tunnel on Dear claim. Analysis by R. D. Hall, University of Wisconsin.

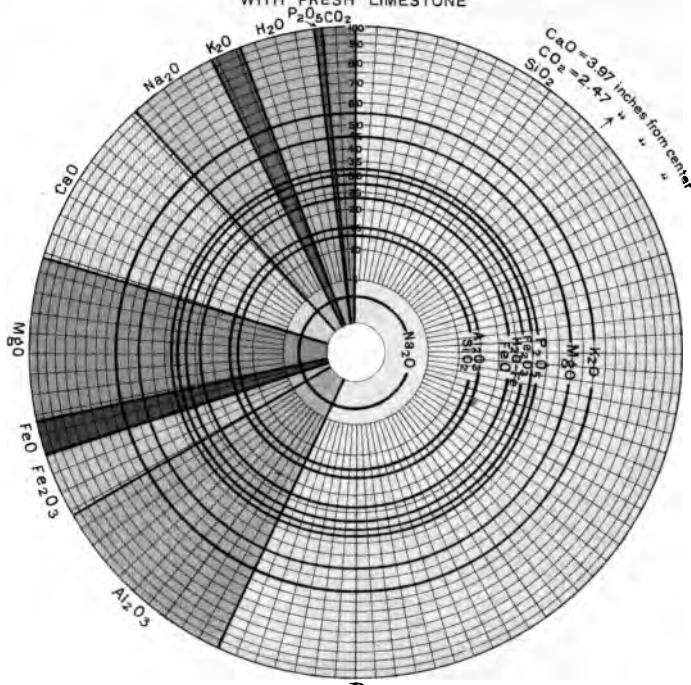


GRAPHIC REPRESENTATION OF COMPOSITION OF FRESH LIMESTONE

GRAPHIC COMPARISON OF COMPOSITION OF ALTERED LIMESTONE, ANALYSIS "H,"
WITH FRESH LIMESTONE (AVERAGE OF ANALYSES "A" AND "B")



GRAPHIC COMPARISON OF COMPOSITION OF ALTERED LIMESTONE, ANALYSIS "I,"
WITH FRESH LIMESTONE



GRAPHIC COMPARISON OF COMPOSITION OF ALTERED LIMESTONE, ANALYSIS "J,"
WITH FRESH LIMESTONE

Mineralogical composition of fresh and altered Homestake limestones, calculated from chemical composition.

Mineral.	Fresh lime-stones.		Altered limestones.					Average of common type of altered limestone (H, I, J).
	A.	B.	H. ^a	I.	J.	K.	N.	
Calcite.....	78.30	72.40	0.50	1.40	3.90	70.80	21.10	1.93
Kaolin.....	4.90	2.58	24.77	11.61	3.09	3.10	.....	13.16
Chert.....	2.64	.....	18.78	1.50	6.30	7.92	34.14	8.86
Actinolite.....	.....	.....	.....	15.55	19.00	.....	.....	11.52
Diopside.....	.....	.....	2.16	20.52	4.32	.....	1.94	9.02
Phlogopite.....	.....	.....	15.57	.....	.....	.....	.....	5.19
Serpentine.....	.....	.....	5.24	4.97	6.76	.....	.....	5.68
Andradite.....	.....	.....	.....	11.20	3.14	.....	.....	4.78
Magnesite.....	5.96	8.65	.....	.....	.....	5.50	.....	.....
Wollastonite.....	6.03	9.86	.....	4.76	3.13	.....	5.10	2.63
Albite.....	.....	.....	16.77	16.24	36.15	1.05	6.81	23.02
Orthoclase.....	.....	.....	.....	8.34	8.89	1.11	3.89	5.74
Limonite.....	1.12	.56	3.74	1.31	2.62	2.62	3.93	2.55
Magnetite.....	.....	.69	3.48	.....	.....	3.48	7.66	1.16
Hematite.....	.....	.....	5.92	.....	.....	.....	9.60	2.03
Enstatite.....	.....	1.00	.....	.....	.....	.....	.....	.....
Apatite.....	.....	.....	.....	.62	.31	.31	4.96	1.24
Pyrite.....	12	.84	.....	.....	.....	.....	.....	.41
Water.....	.16	.59	1.54	.81	2.21	.59	3.53	1.52
Siderite.....	.....	.....	.....	.....	2.32	.....	.....	.....
Witherite.....	.....	.....	.....	.....	.....	.....	.20	.....
	99.23	97.17	99.09	98.52	99.82	99.31	99.14	99.18

^a Contains glass which has been calculated in terms of minerals.

Introduction of ore.—The introduction of ore took place after the development of the silicated contact phase, as is demonstrated by its occurrence in fissures that intersect this phase. The silicated contact phase is found also along parts of the contact where ore is absent. The introduction of ore-bearing solutions effected further metamorphism of the limestone of approximately the same sort, nearly all of the minerals found at the barren contacts being duplicated within and adjacent to the ore itself. (See analyses above.) Apatite, amphibole, biotite, pyrite, and garnet are more abundant in association with the ores than elsewhere in the contact phase, while albite and orthoclase appear in the contact phase and not in the ores. Beyond this it has not been found possible to separate the metamorphic effect of the ore-bearing solutions, aside from its deposition of ore, from the earlier contact effect of the andesite, although it is thought likely that additional careful field work with this object in view might lead to the discovery of further criteria for their separation. The replacement of the limestone by ore is discussed in connection with the origin of the ore (pp. 75-79).

Normal contact phase.—The following paragraphs are devoted to the silicated contact phase, which is described as a unit, without regard to the extent to which it has been developed under the influence of the first contact of the andesite or under the influence of later ore-bearing solutions, although the former is unquestionably dominant.

Analyses of fresh and altered rocks show clearly the net results of the alteration, but they tell little of the extent to which the transfers of materials have been additions or subtractions, unless it is assumed that one substance has remained constant during the change. A variety of inferences are therefore possible, depending upon which substance is selected as a basis against which to measure the changes of the other constituents of the rock. Some substances are easily eliminated as possible constants; for instance, calcium carbonate, in the alteration of a limestone to a silicated rock; for if this material were assumed to remain constant in amount during the alteration, it would require so large an addition of other substances to develop the proportions in the altered rock that the volume would be increased beyond the possibilities of the situation, even allowing for increased density. But other constituents are not so satisfactorily eliminated by such reasoning, and there arises uncertainty and error in the selection from among the various possibilities of the particular substance to serve as a basis of comparison of two analyses. If each substance in turn is considered as constant, the work of calculation becomes tedious and the probabilities of the situation are not easily discerned in the mass of figures and tables obtained.

To meet these difficulties in inferring from analyses the real nature of the rock alterations, the writers present graphic comparisons of the analyses (Pls. IX-XII, *A*), from which it is possible, by assumptions of constancy of any constituent during alteration, to read the percentage gains and losses of other constituents as a result of alteration, and, what is more important, to see at a glance what the probable constants are, without losing sight of the other possibilities.

In the accompanying diagrams a circle with $1\frac{1}{4}$ -inch radius is divided by radii into 100 sectors, each sector therefore representing 1 per cent of the total area of the circle. It is also divided into a series of annuli by concentric circles so spaced ^a that the area of each annulus is equal to 5 per cent of the total area of the circle. The subdivisions of the area, bounded by the sectorial radii and the concentric circles, are therefore equivalent areas and each represents 0.05 per cent of the total area of the circle.

On the base diagram thus constructed, in Pl. IX, *B*, for example, the areas of sectors shown in different colors represent percentage weights of constituents of the altered limestone. Thus silica (analysis H) constitutes about 50 per cent of the altered rock. Of the fresh rock silica (average of analyses A and B) makes up about 7.5 per cent. The ratio of the two is 0.15, and hence the silica of the fresh rock is 15 per cent of the silica of the altered rock. This is indicated on the diagram by the area of the silica sector cut off by the black circle.

^a The area varies as the square of the radius.

marked "SiO," (which may be called the "silica circle"). This circle is drawn with such a radius that its area is 15 per cent of the base circle, and it follows that the portion of the silica sector included is 15 per cent of the whole silica sector.

In the same way the alumina (analysis H) makes up nearly 15 per cent of the altered rock and (average of analyses A and B) about 1.5 per cent of the fresh rock; that is, the alumina in the fresh rock is 10 per cent of that in the altered rock. In the diagram, therefore, the alumina in the altered rock is represented by a sector occupying 15 per cent of the area of the base circle, and to show the relations of that in the fresh rock a circle is drawn so as to include 10 per cent of the total area and consequently 10 per cent of the area of the alumina sector. In a similar manner the relations of the various other constituents in the altered and fresh rock are shown.

The important feature of the diagram is the fact that starting from the silica circle, or the circle representing any other constituent assumed to have remained constant, the actual gains or losses of other constituents may be obtained from the diagram by a simple subtraction.

If silica be assumed constant, the amount of magnesia, for instance, necessary to make up the percentage of magnesia in the altered rock is measured by the area of the magnesia sector included in the silica circle. But on the magnesia sector the magnesia in the original rock is represented by the area of the magnesia sector within the magnesia circle. There are indicated, therefore, both the amount of magnesia required, on the assumption that the silica is constant, and the amount of magnesia actually present in the original rock, which in this case is more than is necessary to meet the required proportion in the altered rock. Magnesia has therefore been lost by an amount measured by the area of the annulus between the silica and the magnesia circles as they cross the magnesia sector. If soda be assumed constant, all constituents other than soda have been lost in amounts measured by the difference between the area of their sectors inside their circles and that inside of the soda circle, which may be taken from radial scale. From the numbers thus obtained the percentage change is readily calculated. If, at the other extreme, calcium carbonate has remained constant, there has been gain of all other constituents, their circles all being smaller than the carbonate circle. Complete or nearly complete removal of a constituent is represented by an arrow.

In general it will be noted that the constituents whose circles lie outside of the circle of the constituent assumed as constant have suffered loss, while those whose circles lie inside have gained. The amount of gain or loss is proportional to the difference between the areas controlled by the superimposed polar coordinates of the several

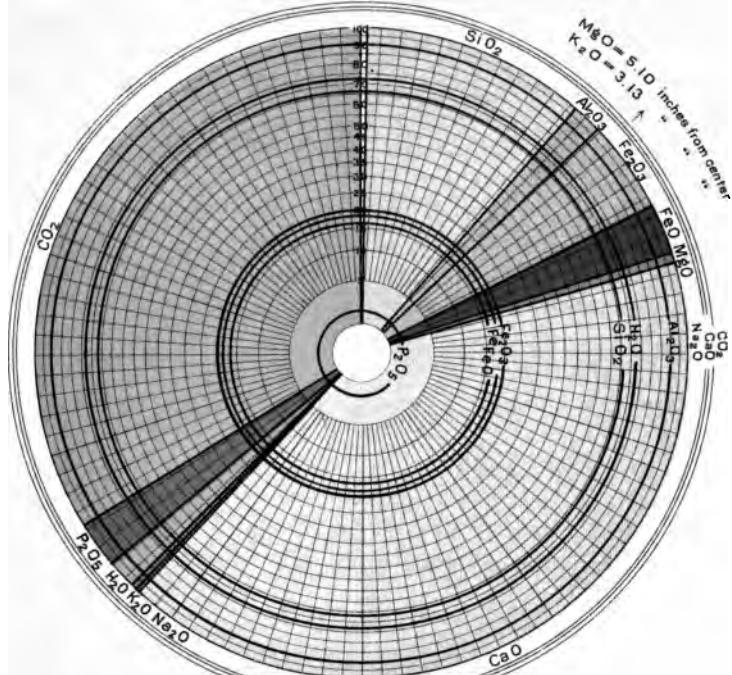
constituents. In practice a comparison of size of circles gives the gains or losses of any constituent against any other constituent, without elaborate calculation.

Where several circles are of nearly the same size, this means that the constituents represented have maintained their mutual proportions during the alteration, and such maintenance of mutual proportions becomes presumptive evidence that the group has remained essentially constant during the alteration and that the change in composition has been effected by gain or loss of other constituents. It may be sufficient, therefore, instead of regarding each of the constituents as possible constants, to consider only those whose ratio circles lie near together. Thus in the present illustration the close grouping of the circles representing silica, alumina, and iron suggests that the constant is to be looked for in this group, and the conclusions then drawn as to the transfers of materials are probably on safer ground than they would be from assumption of constancy of one constituent, without taking into account the additional evidence afforded by the persistence of mutual relations within certain groups. The diagrams have been found also to have unlooked-for value in the recording and comparisons of long series of analyses, affording means for comparison of composites of series of similar alterations, which would involve tedious calculations by ordinary mathematics.

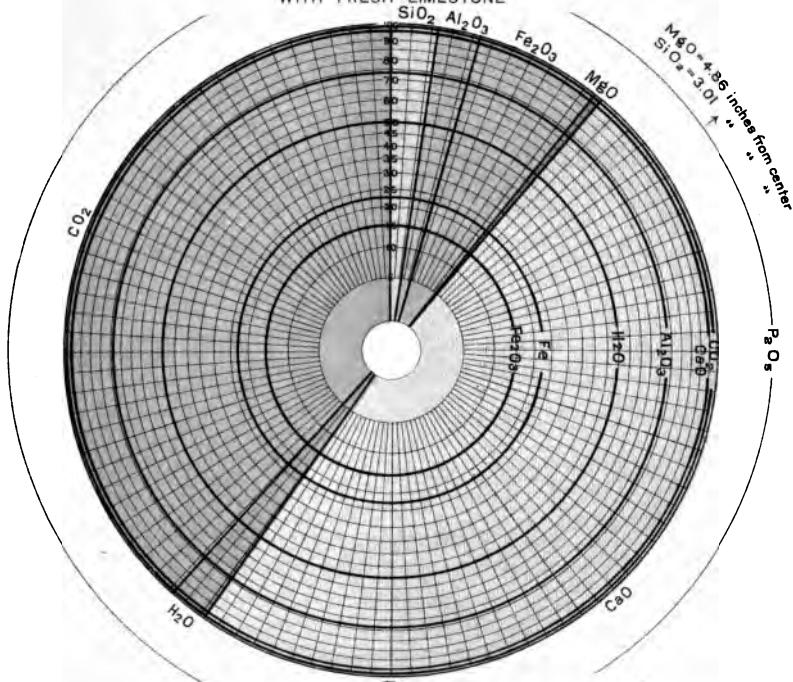
To avoid confusion, it may be stated that the diagrams represent weight alone, and that the gains and losses of weights mean nothing as to change in volume, unless the density is taken into account, as it may be on the same diagrams by a simple graphic device.

The attempt has been made to make the above explanation fairly brief and nontechnical, and not to emphasize the mathematical steps of the process, in order to bring to the reader the real simplicity and usefulness of the diagrams. They are easily grasped and understood by the student when explained empirically, but when the various steps in the construction of the diagrams are mathematically demonstrated the explanation becomes formidable to the nonmathematical reader. For the sake of those requiring more technical explanation the following supplementary account is given:

On the base figure constructed as stated above the percentage composition of any two rocks may be readily represented. For example, in Pl. IX, *B*, if the area of the whole circle be taken to represent a 100-unit mass of the altered rock (analysis H), then the proportional masses or percentages of the several constituents are shown by the areas of the variously colored sectors. Since the area of any sector varies as the arc which subtends it, the size of the sector of any constituent is readily ascertained by laying off an arc proportionate to the percentage of that constituent. The proportional masses or percentages of the several constituents in a 100-unit



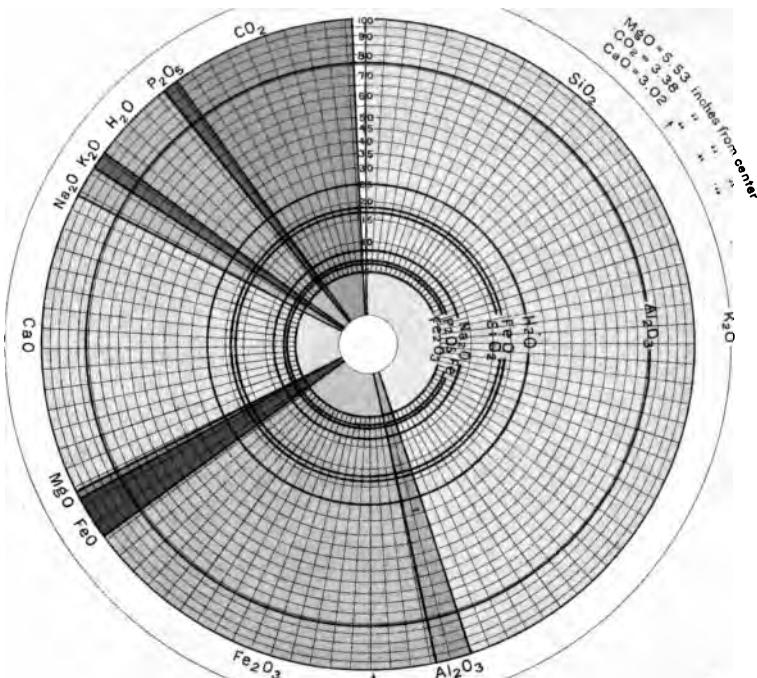
GRAPHIC COMPARISON OF COMPOSITION OF ALTERED LIMESTONE, ANALYSIS "K,"
WITH FRESH LIMESTONE



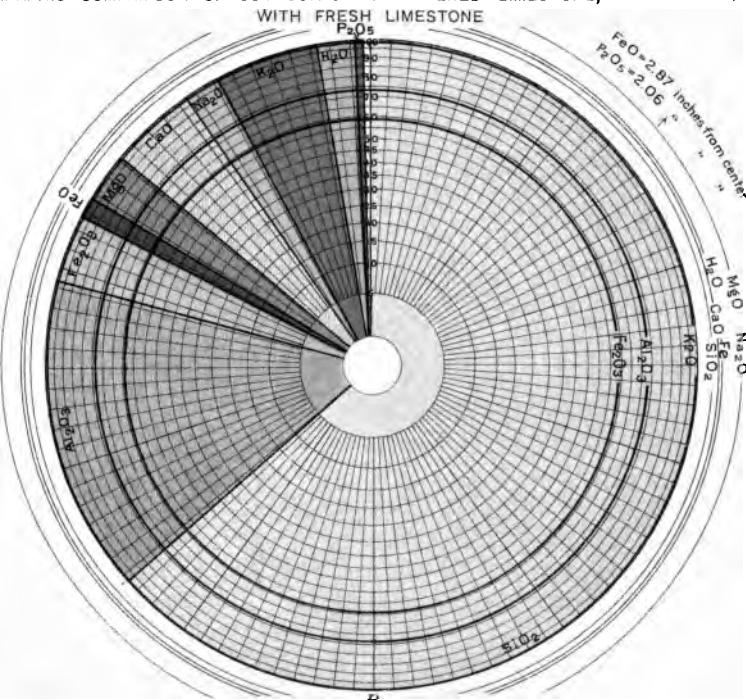
B

GRAPHIC COMPARISON OF COMPOSITION OF ALTERED LIMESTONE, ANALYSIS "L,"
WITH FRESH LIMESTONE

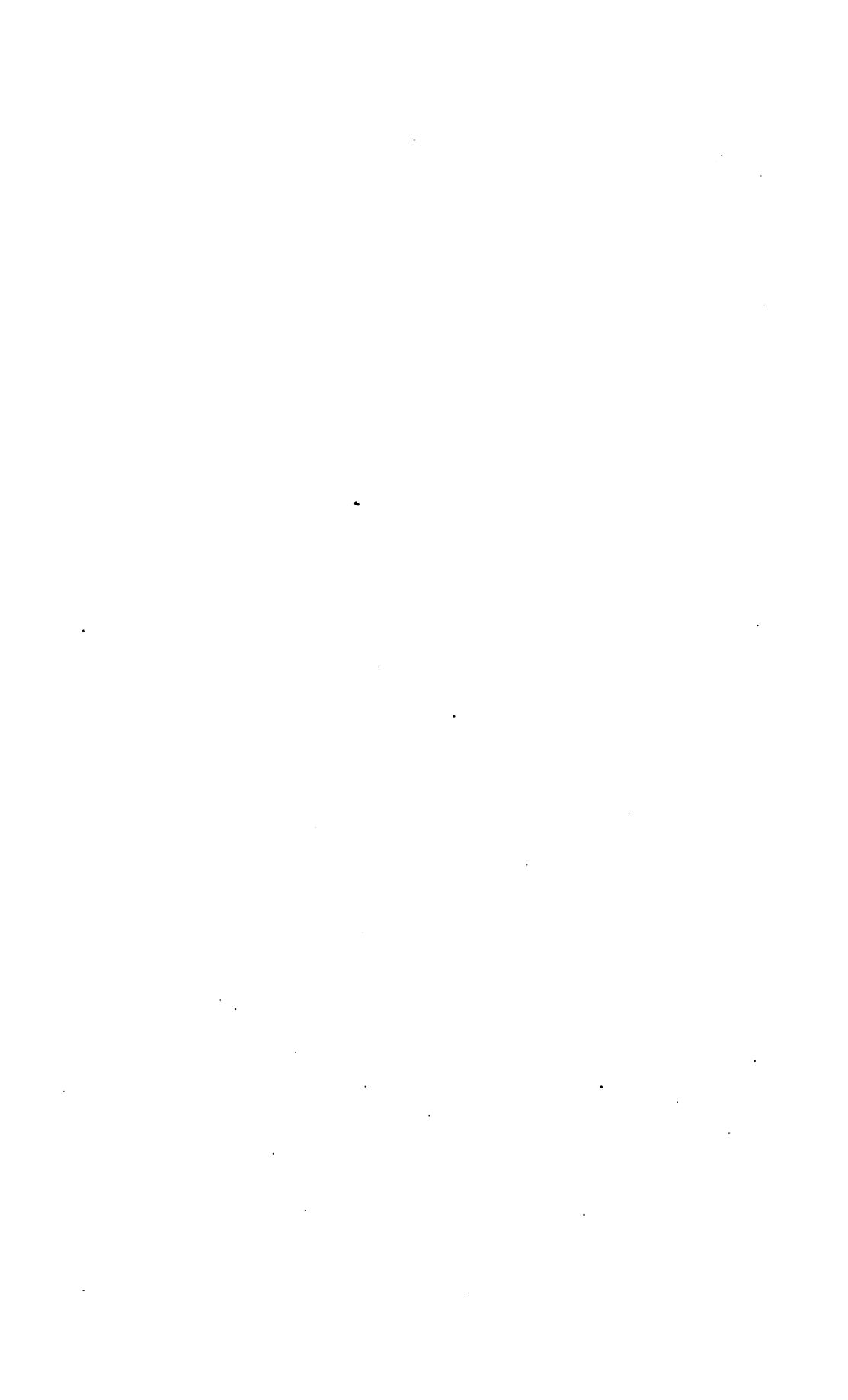




GRAPHIC COMPARISON OF COMPOSITION OF ALTERED LIMESTONE, ANALYSIS "N,"
WITH FRESH LIMESTONE



GRAPHIC COMPARISON OF COMPOSITION OF WEATHERED ANDESITE, ANALYSIS "B,"
WITH FRESH ANDESITE



mass of the original rock (average of analyses A and B) are shown by appropriate areas on the sectors already determined from the analysis of the altered rock. The construction for any constituent is effected by using the ratio of the percentages of this constituent in the original and in the altered rock, as follows: Lay off the determined ratio on the radial percentage scale of the base figure, and through the point thus formed draw a circle concentric with the base circle. The portion of the sector of the chosen constituent lying within the circle thus drawn represents the amount of this constituent in a 100-unit mass of the original rock. In order to make this relation clear, let us consider magnesia as an example. Since the altered rock (analysis H) contains 6.3 per cent of magnesia, take an arc of the base circle equal to 6.3 of the unit divisions. The area of the sector subtended by this arc is 6.3 per cent of the area of the base circle, so that the sector represents the number of unit masses of magnesia present in a 100-unit mass of the altered rock, or, what is the same thing, it represents the percentage of magnesia in the rock. Now, the original rock (analyses A and B) contains 3.7 per cent magnesia and the altered rock (analysis H) 6.3 per cent. The ratio of these numbers, 0.59, expresses the fact that the magnesia in a 100-unit mass of the original rock is only 59 per cent of that in an equal mass of the altered rock. Now, 59 per cent of the base circle and also 59 per cent of any sector lies within the circle drawn through point 59 on the radial scale, so that the area common to the magnesia sector and the 59 per cent circle (which may be called the magnesia circle) is 59 per cent of 6.3, or 3.7, which is the percentage of magnesia which it is desired to represent.

The proportional masses or percentages of the various constituents in both rocks being represented in the manner indicated, the completed diagram furnishes all the factors necessary for making any desired comparisons when it is assumed that the amount of any chosen constituent has remained unchanged.

An example will serve to indicate the principle on which the comparisons are made. The rock of analysis H has been derived by alteration from the rock of analyses A and B. Both analyses are represented on Pl. IX, B. Assume silica to have remained constant, what has been the gain or loss of magnesia during alteration? Apart from the diagram the change in magnesia may be calculated from the data given in the analyses in the following manner: A 100-unit mass of the original rock contains 7.5 units of silica, while a 100-unit mass of the altered rock contains 50 units of the same constituent. Therefore 15 units of the altered rock contain the same amount of silica as a 100-unit mass of the original rock. Now, 15 units of the altered rock contain $0.15 \times 6.3 = 0.95$ unit of magnesia. Evidently there has been a loss, since in 100 units of the original rock there are

available 3.7 units of magnesia. Therefore, $3.7 - 0.95 = 2.7$ represents the number of units of magnesia lost during the alteration, if silica has remained unchanged, and $\frac{2.7}{3.7} = 0.75$, or 75 per cent, the ratio of loss. The number of necessary operations in this calculation may be reduced by using in the place of 3.7 the equivalent expression 0.59×6.3 . Then the formula for the ratio of loss becomes $\frac{(0.59 \times 6.3) - (0.15 \times 6.3)}{0.59 \times 6.3}$, or, eliminating common factors, $\frac{0.59 - 0.15}{0.59} = \frac{0.44}{0.59}$, or 0.75, as before.

Now, by construction, the diagram gives the numbers 59 and 15, which by subtraction gives 44; then $\frac{44}{59}$ gives 0.75 as above; or, converting this decimal fraction into percentage gives 75 per cent as the loss of magnesia during the alteration.

From the above the following rule is derived: To determine the percentage gain or loss of any constituent during alteration, any other constituent being assumed as constant, read on the radial scale the difference between the ratios expressed by the constant-constituent circle and the variable-constituent circle, and divide this by the ratio expressed by the variable-constituent circle. The result will be the percentage gain or loss of the variable constituent. Evidently gains will be shown by ratios greater than unity and losses by ratios less than unity.

We may take up now the specific inferences which may be drawn from the diagrams under discussion.

If calcium has remained constant there has been a great increase of all the other constituents and an increase of weight of the rock. If potassa be assumed constant there has been a considerable gain of all other constituents, except lime, in analyses I and J, and a gain of all other constituents, except magnesia and lime, in analysis H. If magnesia has remained constant there has been a loss in potassa and lime and a gain in other constituents in I and J, and a gain of all constituents except lime in H.

If silica and alumina remain constant this has involved a loss of all constituents except soda. The silica and alumina constants are nearly the same throughout. Soda is the only substance which, considered constant, shows a loss of all other constituents.

Of these various assumptions the constancy of alumina and silica seems to be the most probable. The conspicuous feature in the alteration is the *relative* increase of silica and alumina at the expense of calcium carbonate. This means either (1) that silica and alumina have been introduced from without to replace the calcite, in which case there may not have been any considerable change in the volume

of the rock during alteration; or (2) that calcite has been taken out of the fresh limestone, leaving the silica and alumina in larger proportion, in which case the weight and, as will be shown later, the volume has considerably decreased; or (3) some combination of these two methods has accomplished the same result. Alternative 2 is favored by the fact that, while the alumina has gained slightly in percentage on the silica, the ratio of the two substances in the fresh and altered rocks remains substantially the same, in the fresh rocks average alumina standing to silica as 19 to 100, and in the altered rocks as 21 to 100. (See analyses, pp. 26-27, and Pl. X.) The near accordance of the alumina and silica circles in Pl. X brings out well the uniformity of the ratio. If silica and alumina have been added from without, it is a remarkable coincidence that they should have been added in so nearly the same proportion as in the fresh rock, especially when it is remembered that their proportion in the fresh limestone is not determined by silicate ratios but rather by the abundance of chert.

On the assumption that alumina remains constant, it will be noted that the greatest percentage lost is calcium, next magnesia, then potassa, and then silica, which is the order of solubility of these substances in weathering. The only exception is soda, which without much question has been introduced into the contact phase. It will be noted further that the composition of the altered rock is essentially that of a calcareous residual clay.

Comparison of average fresh Homestake limestone with normal contact phases, with alumina (Al_2O_3) assumed to be constant.

	A. B.	H.		I.		J.		H, I, J.	
	Average, fresh.	Altered.	Variation from A, B.	Altered.	Variation from A, B.	Altered.	Variation from A, B.	Average.	Variation from A, B.
SiO_2	7.49	5.168	- 2.322	8.313	+ 0.823	8.62	+ 1.13	7.367	- 0.123
Al_2O_3	1.49	1.49	0.00	1.49	0.00	1.49	0.00	1.49	0.00
FeO.....	.95	1.172	+ .222	.812	- .138	.468	- .482	.817	- .133
FeO.....	.41	.115	- .285	.385	- .025	.271	- .139	.290	- .120
MgO	3.60	.648	- 3.042	1.502	- 2.088	1.233	- 2.467	1.127	- 2.563
CaO	46.91	.126	- 46.784	2.313	- 44.597	1.301	- 45.609	1.243	- 45.665
Na_2O.....	.13	.206	+ .076	.310	+ .180	.649	+ .519	.388	+ .258
K_2O.....	.85	.432	- .418	.225	- .625	.236	- .614	.298	- .414
H_2O	1.03	.716	- .314	.527	- .503	.588	- .442	.610	- .419
P_2O_5.....	.04	.032	- .008	.019	- .101	.019	- .021	.023	- .043
CO_2	37.01	.021	- 36.989	.100	- 36.91C	.263	- 36.747	.128	- 36.882
	100.00	10.126	89.864	15.996	83.984	15.138	84.872	86.104	- 13.791

Exceptional contact phases.—These phases represent introduction of calcite, iron, and silica. Analysis L is of an iron-stained marble in a vein. Probably all of the constituents are secondary, but if the alumina or silica is the same as in the fresh limestone, there has been a considerable introduction of iron and a slight loss of calcite and soda, or if alumina has remained constant there has been also a gain

of silica. Sample N is a contact phase of the limestone in which there has been conspicuous introduction of soda, silica, water, and iron and loss of calcite and potassa. K is an intermediate stage between the fresh limestone and N.

General result of alteration.—It is concluded that in general there has been large loss of material from the limestones at the contact without conspicuous introduction of new material except soda, but that exceptional phases show clearly the introduction of silica and iron. Both normal and exceptional phases of the contact rocks are cut by later veins of calcite and iron ore, with associated minerals similar to those of the limestone contact. (See p. 85.)

Changes in density and volume during contact metamorphism.—Specific-gravity determinations of the fresh and contact phases of the Homestake limestone are as follows:

Specific gravities of fresh and contact phases of Homestake limestone.

	Fresh lime-stone.		Contact phase.			Average of 5 specimens from contact, including H, I, J, and L.	Average of fresh limestones.	Average of all contact phases.
	A.	B.	H.	I.	J.			
Specific gravity determined from mineral calculations.....	2.739	2.775	2.74	2.93	2.73	.....	2.76	2.86
Specific gravity determined from hand specimens.....	2.705	2.706	2.22	2.59	2.57	2.56	2.70	2.56
Specific gravity determined from powdered specimens.....	.....	.....	2.20	2.92	2.68	.....	.....	2.60
Pore space calculated from specific gravities of hand specimens and powdered specimens.....	.....	.....	10.2	4.1	.....	.....	2.2	7.1

The difference between the gravity determined in the hand specimen and that in the crushed specimen measures the pore space. The fresh limestone when powdered is slightly soluble in water, vitiating gravity determinations. In this case the difference between calculated and measured gravities measures the pore space, for there is little chance for error in the computed gravity. The only altered rock not having pore space, H, is made up largely of glass. Taking the glass into account, there has been little average increase of pore space in the contact rocks as a group, if the analyses represent proper proportions of contact phases. Leaving this out of consideration, the pore space at the contact has increased slightly, from 4 per cent to 10 per cent.

The calculated specific gravities correspond fairly well with those determined from the powdered specimens, affording a check on the computation of the mineral composition from the chemical analyses. Sample H is again an exception because the contained glass has a specific gravity considerably lower than that computed from the possible mineralogical composition based on chemical analysis. By

eliminating from consideration the mica and iron oxide observed in the glass, it is easy to determine from the measured density of the rock that the density of the glass is not far above 2. Thus the theoretical complete crystallization of glass or fused equivalent in the contact phase of the limestone has involved a diminution in volume of perhaps 19 per cent, or about 15 per cent if pore space be taken into account.

It may be concluded in general that the actual density of the altered rocks is less than that of the fresh limestone, largely because of the development of pore space and glass, but that the densities of the minerals of the altered rocks are on the whole slightly higher than those of the fresh limestone.

Exceptional contact phases, consisting almost entirely of silica or garnet or other constituents, give other density results.

If the principal chemical change in the development of the contact phase has consisted in the elimination of calcite and to a less extent of magnesia, iron, and potassa, leaving alumina and silica substantially unchanged in their ratios, as held to be possible in an earlier paragraph (p. 32), this has involved a very considerable loss of weight (see analyses, p. 27), and, as the densities of the fresh and altered rocks differ so little, the loss in volume also has been large. Kemp,^a Lindgren,^b and others have cited lack of structural evidence of diminution in volume at limestone contacts as favoring the view that materials must have been introduced from without to take the place of the calcium carbonate. In the Iron Springs district the field evidence does not positively prove or disprove important volume change, but there is no apparent field evidence to contradict the evidence for diminution of volume here calculated. The limestone, though tilted away from the andesite laccoliths, nowhere shows evidence of crumpling or crowding where the bedding can be observed. In the altered phase the bedding has been destroyed, and it is easy to conceive that this structurally amorphous zone may represent only a part of the volume of the original rock, the calcium carbonate having been driven off and the other constituents concentrated. The change in volume of the limestone would scarcely be expected to stand out conspicuously in the field relations, for it has occurred, if at all, in the band which now does not show original textures or structures, by which change of volume can be measured in crumpling or folding.

In general it appears that there may have been important diminution of volume, accomplished essentially by loss of materials and not by change of density of minerals.

^a Kemp, J. F., Ore deposits at the contacts of intrusive rocks and limestone and their significance as regards the general formation of veins; *Econ. Geol.*, vol. 2, 1907, pp. 1-13.

^b Lindgren, Waldemar, The copper deposits of the Clifton-Morenci district, Arizona; *Prof. Paper U. S. Geol. Survey No. 43*, 1905, 375 pp.

Physical conditions of contact metamorphism.—The andesite in its molten state may be supposed to have had a temperature common to acidic silicate solutions under similar conditions anywhere from 500° C. up; probably above 1,000° C. After sufficient heat had been communicated to the limestone to raise the temperature to 550° C., expulsion of carbon dioxide began, and continued during the subsequent increase in temperature. For any given temperature above 550° C. expelled carbon dioxide has a definite pressure which must find relief, if liberation of the carbon dioxide is to continue. The nearly complete elimination of carbon dioxide along the andesite contact indicates that the pressure was not sufficient to restrain its exit; that the pressure was therefore small; and that continuous openings for escape to the surface probably existed.

When the temperature reached 1,100° C. there probably began the incipient fusion of the alumina, silica, lime and magnesia, which remained in the limestone in about the proportions of a calcareous clay. The presence of lime in clay permits fusion at about this temperature.^a The pore space in the limestones, possibly increased by the expulsion of carbon dioxide, was eliminated, probably in part by pressure, but certainly and completely by fusion. Had the temperature not reached 1,100° it is possible that a porous texture would have resulted, such as that sometimes seen along the limestone contacts with igneous rocks,^b which would have favored the introduction of new substances in the contact phase to a larger extent than is here observed.

After the limestone reached its maximum temperature, probably somewhat below that of the andesite magma, the temperature slowly fell, allowing fairly coarse crystallization of both andesite and limestone. Local chilling, however, developed glass in parts of the fused limestone mass, and the glass remains, at least in part, to-day. The introduction of the ore-bearing solutions accompanied or followed the crystallization, and still later came the mineral-bearing waters from the late lavas. The minerals of these different periods are listed on page 85.

SANDY PHASE OF LIMESTONE.

The altered contact phases of limestone are often hard to distinguish from a much-fractured quartzite or clayey sandstone which is locally exposed below the limestone and constitutes a part of the same formation. The sandstone lies between the ore deposits and the andesite, or between the ore and the limestone. It is conspicuous also in the limestone patches faulted into the andesite. In

^a Ries, Heinrich, and Kümmel, H. B., The clays and clay industry of New Jersey: Final Rept. State Geologist New Jersey, vol. 6, 1904, p. 103.

^b Barrell, Joseph, The physical effects of contact metamorphism: Am. Jour. Sci., 4th ser., vol. 13, 1902, pp. 279-296.

the large-scale detail maps of the ore deposits (Pls. III-VI, in pocket) the lower sandy phase and the metamorphosed phases of the blue limestone have been separated from the typical blue limestone but not from each other.

Unless the structural relations are clear, both the sandy and silicified contact phases of the limestone are likely to be confused with the Cretaceous sandstone which occurs in isolated patches in the andesite.

FOSSILS.

The fossils found in the Homestake limestone are few and poorly preserved. Only one genus, *Aviculopecten*, ranging from Silurian to Triassic, was identified by Prof. Eliot Blackwelder, of the University of Wisconsin. There are fragments, however, which appear to be referable to *Edmondia*, a Carboniferous genus.

STRUCTURAL RELATIONS AND THICKNESS.

The Homestake limestone is intruded by the laccoliths. The contacts are usually nearly vertical, sometimes because of later faulting. In a few localities, as at the Desert Mound, in the southwestern part of the Iron Mountain laccolith, and south of The Three Peaks, the limestone rests against and upon the laccolith with a gently dipping plane of contact, though locally even here the contacts are steep because of faulting. In the circular ridge east and southeast of the Iron Mountain laccolith the dip of the Pinto sandstone and the Claron formation is steeply toward the andesite, suggesting an overturned fold in which the Homestake limestone probably participates.

The Homestake limestone is overlain conformably by the Pinto sandstone, with a shale at the base.

The thickness of the Homestake limestone, as shown by exposures, ranges from 500 to 50 feet. The average thickness has been taken to be about 200 feet. The variation is probably due to intrusion of laccoliths at different horizons. If the intrusion has followed the base the variation in thickness may indicate unconformity with the overlying Pinto sandstone.

CRETACEOUS SYSTEM.^a

PINTO SANDSTONE.

DISTRIBUTION.

The Pinto sandstone for the most part borders the Homestake limestone on the side away from the laccoliths. On the west side of The Three Peaks it extends several miles westward from the band of Homestake limestone and disappears under the desert clays and

^a Jurassic in part, perhaps.

gravels. On the southwest end of The Three Peaks laccolith the Pinto sandstone is in contact with the andesite in several places, but farther east it again appears in its normal place outside of the Homestake limestone, and continues until covered by the later clays. The formation borders the north, east, and south sides of the Homestake limestone and the andesite of Granite Mountain, and a tongue extends northward into the desert. South and west of the Desert Mound there are also considerable exposures. Patches are exposed south and about three-fourths of a mile northwest of Iron Springs.

In the southwest quarter of the district a belt of Pinto sandstone extends around the Iron Mountain laccolith, widening out to the west and southwest. A small area is found southwest of the Homestake mine, within the area of the Iron Mountain laccolith. North of Iron Mountain there are several small areas of sandstone exposed outside of the Claron limestone surrounding the Antelope Range lavas. A belt surrounds the Stoddard Mountain intrusive, which is just on the southern edge of the area mapped.

CHARACTER.

The Pinto formation is composed mainly of brown, yellow, gray, maroon, and spotted sandstone, both coarse and fine grained. Interstratified with these in the lower part of the formation are maroon, purple, and green shales, a few beds of conglomerate, and a few of gray, sandy, brecciated limestone. None of these interstratified beds are continuous throughout the area. In the Granite Mountain and Three Peaks areas the lower part of the Pinto formation has a characteristic succession, only a few members of which are present in the area about Iron Mountain. A generalized section for the first two areas is as follows:

Generalized section of Pinto formation in Granite Mountain and Three Peaks areas.

	Feet.
7. Yellowish brown and gray sandstone	1,000+
6. Conglomerate with interbedded sandstone	20-40
5. Variegated sandstone and shale	40-75
4. Conglomerate	8
3. Cherty limestone breccia	10-20
2. Maroon and spotted sandstone	40-60
1. Purple and green shale	30-50

The shales (1) at the bottom, in contact with the Homestake limestone, are fairly continuous, being found throughout the northeast quarter of the district, and at one locality east of Iron Mountain, though here only the green shale is present. They are soft, sandy, and much fractured.

The maroon and spotted sandstones (2) are abundantly exposed in the northeast quarter of the area, but appear locally at other points,

as east of the Homestake mine, south of Crystal Springs, and around the southwest corner of the Iron Mountain laccolith. They are comparatively soft and friable and are generally of a deep maroon color; at the base are beds of white sandstone having deep red spots. The grains are mostly quartz and the different colors are due to iron oxide in the cement.

The cherty limestone breccia (3), although thin, is another characteristic bed in the lower part of the Pinto formation. It is present around The Three Peaks laccolith, north of the Granite Mountain laccolith, and east of the Desert Mound, at all of which places it occupies the same part of the series. It is a dark grayish-blue brecciated limestone. The fragments vary in dimensions from a fraction of an inch to 6 inches, and are separated by narrow bands or veinlets of chert, which on weathered surfaces may project as much as a quarter of an inch above the rest of the rock. Under the microscope the fragments appear to be made up of exceedingly fine grains of calcite, with here and there veins of coarser calcite.

The lower conglomerate (4) is associated, almost without exception, with the brecciated limestone, but it is also found in parts of the district where the latter is not present. Wherever identified it has been mapped with the conglomerate symbol. It is exceedingly well cemented, so that on breaking, the fractures occur for the most part through the pebbles instead of around them. This is true especially in the northeast quarter of the area. The pebbles are chiefly quartz, black chert, quartzite, and dark limestone, the latter probably being obtained from the Homestake formation. The matrix is composed of rather fine-grained sand, the whole being well cemented by silica.

Between the lower and upper conglomerates there are a number of sandstone and shale beds (5), none of which are continuous over any considerable area. West of The Three Peaks the lower part is characterized by light-green shale about 20 feet in thickness, overlain by a purple shale about half as thick. Above this are fine-grained flaggy sandstones, white, gray, and mottled in color. West of Granite Mountain and south of The Three Peaks the shales are entirely absent, being replaced by coarse- and fine-grained sandstone.

The upper conglomerate (6) appears throughout most of the northeast quarter of the area. It consists of heavy conglomerate layers alternating with thin layers of sandstone, the pebbles composing the former being of the same kind as those of the lower conglomerate but as a rule larger, especially where the formation is thick, and less firmly cemented. Around the Iron Mountain laccolith only one conglomerate is present, presumably the lower, since at several places a maroon sandstone is found between it and

the Homestake formation. In the northeast quarter of the district this conglomerate also has been mapped.

Above the conglomerate beds throughout the district is a great thickness of gray, yellowish-brown, or red sandstones (7), forming by far the largest part of the Pinto formation. These are normally coarse and friable, but where parts of the Pinto formation come in contact with the laccolithic andesite they are fine grained and quartzitic. The sandstone becomes coarser in its upper part, and near the top contains a layer of coarse conglomerate. During the erosion interval at the end of the Cretaceous this conglomerate was so largely removed that at present it is found only locally near the overlying Eocene deposits.

Limestone lenses appear in the Pinto sandstone along the southwestern edge of The Three Peaks, immediately southwest of Iron Springs, and in the middle of the valley halfway between these areas. Other lenses are exposed in Oak Springs Flat, east of Iron Mountain, where they are partly obscured by late unconsolidated deposits. These lenses are in the lower part of the Pinto formation, but their exact position in the preceding succession is not known.

The limestones are much fractured and brecciated. Their color varies, in different parts of the district, from dark gray to light gray and even pink. The latter is very much like the Claron limestone and is distinguished from it only by its brecciated character.

CONTACT METAMORPHISM BY LACCOLITHS.

At or near the contact of the Pinto sandstone with the laccolithic andesite the sandstone is quartzitic, and the yellow, brown, and red colors are replaced by gray and white. In places the rocks are mottled or have concentric dark-colored rings (Pl. XXI, A, p. 74), which, under the microscope, appear to be irregular aggregates of small elongated crystals of colorless amphibole. The metamorphism is commonly noticeable for a few hundred yards from the contact, and west of Iron Mountain it is seen as far as a quarter of a mile.

FOSSILS.

No fossils were found in the Pinto sandstone. This absence of fossils and the association of red sandstones and shales suggest terrestrial deposition.

STRUCTURAL RELATIONS AND THICKNESS.

The relations of the Pinto sandstone to the underlying Homestake limestone have already been discussed. The relations with the overlying Claron formation are unconformable, as evidenced by a basal conglomerate and by the partial erosion of certain well-recognizable beds near the top of the formation. There seems to be

little unconformity of dip, however, indicating that the period of erosion between Cretaceous and Tertiary was not characterized by folding.

In general the Pinto sandstone dips steeply away from the laccoliths, but south of The Three Peaks, at the Desert Mound, and west of Iron Mountain the dip is gentle. East of Iron Mountain the dip is steeply toward the laccolith; to the southeast it gradually becomes vertical; and south of Iron Mountain it is steeply away from the laccolith. East of Upper Point, south of Joel Springs Canyon, and elsewhere the beds are nearly horizontal.

It is hard to determine the thickness of the Pinto formation because of the abundance of faults. The greatest thickness exposed in cliffs is about 500 feet, but thicknesses across the formation southeast of Iron Mountain, calculated from the dip and width of exposure, are as high as 3,500 feet. The average thickness is considerably over 1,000 feet.

TERTIARY SYSTEM (EOCENE).

CLARON LIMESTONE.

DISTRIBUTION.

The Claron formation surrounds the laccoliths outside of the Pinto sandstone. In the northeast quarter it occupies an area just inside of the north boundary of the area shown on the map. It is much faulted, giving an irregular contact between it and the Pinto sandstone to the south.

East of Granite Mountains the Claron limestone occupies an area which, on account of faulting, is broad at the north and narrow at the south and west. Narrow strips of the formation follow the northwestern base of the Swett Hills.

Southwest of the Antelope Range the Claron limestone comes out from underneath the lavas and extends eastward to where it is covered by the Pleistocene lake deposits and southward to where it has been eroded away from the underlying Pinto sandstone. In Chloride Canyon, southwest of the Antelope Range, and northwest of Iron Mountain it appears again, owing to the erosion of the overlying lavas.

The largest area of Claron limestone in the district borders the eastern and southern sides of Iron Mountain, then goes outside of the area, but reappears west of Iron Mountain, on the border of the area shown on the map. Both by its distribution and by its structure it brings out well the laccolithic shape of the andesite mass.

On the northeast side of the Harmony Mountains little areas of Claron limestone are brought up by faulting. It appears also west of the Stoddard Mountain intrusive.

CHARACTER.

The Claron formation is mainly limestone with numerous thin layers of conglomerate and a few heavy beds of sandstone. It is separated from the Cretaceous sandstones by a basal conglomerate 2 to 25 feet thick, made up of coarse quartzite pebbles where it is thick and of finer pebbles where it is thin. Below it is generally a soft, pink, calcareous sandstone or soft limestone, which probably represents residual material from the weathering of the Pinto formation formed before the deposition of the Eocene. It is only a few feet thick and under it are the red and yellow sandstones of the Cretaceous. Locally the underlying Cretaceous bed is a coarse conglomerate difficult to distinguish from the basal conglomerate of the Claron formation. In most places it was eroded away before the deposition of the Claron. Above the basal conglomerate is another conglomerate, thin and sandy, with small pebbles, and discontinuous. It is like numerous other conglomerates interbedded with the limestone higher up in the formation. These as a rule are thin and any single bed is not continuous over a large area. The pebbles are small and are separated by a matrix of coarse sandstone. They are mainly quartzite, limestone, quartz, and chert, in varying proportions in the different beds. The conglomerate beds may grade laterally into coarse sandstone beds.

The principal part of the formation is a sandy limestone varying from white and gray to pink, red, and purple. On weathering, the sand grains, being less easily dissolved, protrude above the surface and give it a rough pitted appearance. Some of the layers have spherical and irregular cherty concretions which vary from less than half an inch to an inch or more in diameter. The limestones are more resistant to erosion than the sandstones and conglomerates of the Eocene and Cretaceous, and hence form cliffs and ridges above them. On weathering they acquire bright-red colors, making the exposures conspicuous for many miles.

Heavy yellowish-brown sandstone beds containing a number of discontinuous layers of conglomerate are interbedded with the limestones. Owing to faulting, it is hard to tell the thickness of these sandstones, but it may be several hundred feet. In some places they are distinguished with difficulty from the Cretaceous sandstone. Criteria for their identification are their occurrence in the midst of Tertiary rocks, and the absence of a basal conglomerate between them and the overlying limestone and conglomerate beds. The first of these might be caused by faulting, but the invariable absence of the basal conglomerate in such cases was taken as evidence that they were Tertiary.

FOSSILS.

No fossils were found in the Eocene limestone, but a number were found in the limestone and chert pebbles of the conglomerate beds. The following forms, which are mainly Carboniferous, were identified by Prof. Eliot Blackwelder:

Fossils from the Claron limestone.

Productus sp.	Spirifer sp.
Fenestella sp.	Zaphrentis sp.
Lithostrotion sp.	Crinoid stems and bryozoans.
Rhynchonella sp.	

They show only that the Claron sediments are post-Carboniferous.

STRUCTURAL RELATIONS AND THICKNESS.

The relations of the Claron limestone to the underlying Pinto sandstone have been discussed. On the upturned and eroded edges of the Claron limestone lie the Tertiary lavas in nearly horizontal beds.

The dips of the Claron limestone are slightly less than those of the Pinto sandstone because of their greater distance from the laccoliths. In a few places the beds are nearly horizontal, as south of Joel Springs Canyon and at Mount Claron.

A large amount of faulting has taken place in Eocene areas, some of which has undoubtedly remained undetected because of the similarity of different parts of the formation. Most of it dated after the laccolithic intrusion and before the later lavas were poured over the area, as shown by the fact that certain of the limestone areas are much faulted while the adjacent lava beds are undisturbed. A few faults traverse both formations indiscriminately, thus showing a later period of faulting.

The thickness of the Claron formation varies in different parts of the quadrangle, owing to erosion both before and after the laccolithic intrusion. The average thickness is about 1,000 feet, but all estimates are largely vitiated by faulting.

CONTACT METAMORPHISM BY EFFUSIVES.

Adjacent to the lavas the limestone has a layer of white, gray, or red chert, chalcedony, and moss agate or jasper, which is sometimes 10 to 15 feet in thickness. The red moss agates and jaspers are colored with iron. With these cryptocrystalline varieties of quartz is often associated a white powdery calcium carbonate, apparently deposited by hot springs. This is especially abundant north of the Eightmile Hills. The same powdery carbonate is frequently associated with the ore deposits.

At Chloride Canyon and elsewhere the limestone contains mineral veins near the contact with the lavas. The minerals are mainly calcite, barite, and quartz, with subordinate amounts of galena, pyrite, chalcopyrite, siderite, limonite, magnetite, and copper carbonates. Gold and silver are reported, the latter probably being present in the galena. Similar mineral veins are found in the Homestake limestone, both associated with and away from iron-ore deposits.

QUATERNARY SYSTEM.

PLEISTOCENE CONGLOMERATE.

The Pleistocene conglomerate is exposed only east of Antelope Springs, in the northwest corner of the area, where it occupies a little embayment in the lava area. To the north it is covered by later lake and outwash deposits. In the Pleistocene conglomerate area a few exposures of Tertiary limestone and conglomerate were noted, but it was not possible to tell whether these were outcrops of actually underlying formations or merely huge boulders partly buried. There being no definite proof of the former, these exposures were not mapped. The formation is probably present west of The Three Peaks, overlying the Cretaceous and overlain by surface deposits, but only one outcrop was found and this was too small for the scale of the map.

The conglomerate is composed of both rounded and irregularly shaped fragments of limestone, chert, sandstone, and lavas, derived from immediately adjacent rock formations and cemented by a reddish sandy calcareous material, forming in places a fairly well-consolidated rock. It is rather thinly bedded, some of the beds being made up of coarse conglomerate, and others of finer sandy materials. From the thinly bedded character and rapidly varying materials of the different beds it seems clear that the formation is of fluviatile or terrestrial origin, deposited by streams as they emerged from the mountainous areas.

The Pleistocene conglomerate is unconformable upon the Tertiary lava series, in horizontal beds which retain no evidence of faulting. Its thickness is not known, but it is likely not more than 200 feet at the most.

PLEISTOCENE AND RECENT GRAVEL, SAND, AND CLAY.

Gravel, sand, and clay, derived from the neighboring rock hills, cover the lower slopes of the hills and the desert areas as lake, stream, and outwash deposits. To the east are the deposits of Rush Lake Valley, which run northeastward along the Colob front. To the west and north are the deposits of the Escalante Desert, which extend 35 or 40 miles westward and far to the north.

In the Escalante Desert clay is found mainly along the washes and in the low areas bordering them, while the gravels and sands are found in the areas between the washes. These coarser materials are fairly well rounded and appear to have been sorted.

The area around Shirts Lake is composed of fine clay with a white coating of alkaline carbonates. Around the entrance to Leach Canyon and in Rush Lake Valley east of Iron Springs are rolling hills of coarse subangular and rounded gravels, similar to those in the Escalante Desert.

Outwash fans of fine and coarse angular material border all the hilly areas and extend out into the desert for half a mile or more. Some of these are perfectly fan shaped, but in general the separate fans encroach upon one another laterally and form continuous outwash aprons along the borders of the hills. They have a relatively steep slope near the hills and gradually become less steep until they merge imperceptibly into the flat deserts.

These are the latest deposits in the area, and they are still accumulating. Their thickness is not known.

CHAPTER IV.

IGNEOUS ROCKS.

The igneous rocks of the district are both intrusive and effusive. The intrusives are biotite andesite laccoliths intruded into the Paleozoic and to a less extent into the Mesozoic rocks after the deposition of the Tertiary sediments. The effusives are later and form a bedded series varying in thickness from 1,000 to 2,000 feet and consisting of rhyolitic, trachytic, and andesitic flows, tuffs, and breccias.

The lavas rest on the eroded and upturned edges of the Eocene and Cretaceous sediments, indicating a considerable period of erosion between the intrusion of the biotite andesite and the outpouring of the effusives. The latter have been correlated with the Miocene lavas of the Wasatch Mountains, hence the andesite intrusion is post-Eocene and probably early Miocene.

The Quaternary basalts, present on all sides of the area, are not present within the district.

LACCOLITHS (EARLY MIocene).

DISTRIBUTION AND STRUCTURE.

The laccoliths are exposed in three main areas forming the cores of the principal mountains of the district—The Three Peaks and Granite Mountain in the northeastern and Iron Mountain in the southwestern part. A fourth, Stoddard Mountain, lies mainly beyond the southwest side of the area mapped. The laccolith areas are circular, with local irregularities due to faulting and other causes. Northwest of the The Three Peaks a small area of biotite andesite is brought up in contact with the Claron limestone by a great fault. Northwest of Iron Mountain a wide dike of andesite breaks through the Pinto sandstone a short distance from the main laccolithic mass, while to the southwest, surrounded by sediments, are several small andesite areas, parts of the large andesitic mass exposed through erosion of the low-dipping overlying limestone. In The Three Peaks and Iron Mountain laccolithic areas there are small patches of sediments faulted down into the andesite or left as erosion remnants.

In general the sediments dip away from the andesite, although locally, as east of Iron Mountain, the dip is steeply toward it, suggesting overturned strata. The strike of the beds is always parallel, or nearly so, to the andesite contact, except where faulting has

caused irregularities of structure. Individual strata of sediments may be followed almost entirely around the andesite areas. The contact with the sediments is commonly steep and the dip of the sediments less steep. Less commonly both the dip of the contact and of beds is low. The dip of beds and contact varies with depth of erosion. Nowhere has erosion exposed the base of the laccoliths, though the tops are well stripped. The maximum thickness exposed is 1,600 feet.

The circular outline of the intrusions, the manner in which the sediments encircle them and rest against and upon them, and the texture of the andesite favor the view that they are laccoliths (Pl. II, pocket). With their relations to the sedimentary rocks, the only alternative explanation would be that of a batholithic intrusion, and against this stands their texture and the lack, in the surrounding sediments, of the schistosity that often characterizes a plutonic contact. It is with some confidence, therefore, that the andesite masses are concluded to be laccoliths, notwithstanding the lack of direct observation of shape of the lower parts.

According to Gilbert's study of the laccoliths of the Henry Mountains,^a the pressure of injection remaining constant, the limital area of a laccolith is a direct function of its depth beneath the surface. The limital area is greater when the depth is greater, and less when the depth is less. A laccolith with the diameter of the Iron Mountain laccolith would require a minimum of 7,000 feet of covering. A possible covering of about 4,500 feet can be measured on the eroded edges of the surrounding sediments. If Gilbert's conclusion be a sound one, it may be inferred that in the Iron Springs district certain sediments have been completely removed by erosion. His calculation, however, is based on the assumption that the sediments have been elastic and free to slide one over the other during the intrusion. If, on the other hand, the overlying sediments have any considerable strength, developing resistance beyond that afforded by the weight, the size of the laccolith would be proportionally increased. Such resistance may well be possessed by the Homestake limestone, which in all but a few places immediately overlies the laccolith, and the large size of the Iron Springs laccoliths may be due to this cause rather than to any greater depth of covering than can be measured on the sediments now present in the area.

A similar conclusion as to the factors determining the horizon of the laccoliths is reached from a consideration of densities. The density of the andesite is 2.65. The mean density of the rocks known to overlie it is about 2.54. Gilbert argues for the Henry Mountains that the laccoliths came to rest in such a position that their density

^a Gilbert, G. K., Report on the geology of the Henry Mountains: U. S. Geog. and Geol. Surv. Rocky Mtn. Region, 2d ed., 1880, p. 84.

is slightly above the mean density of any combination of the overlying sediments. The density of the Iron Springs laccoliths, now 2.65, was considerably lower before solidification, presumably lower than 2.54, the mean density of the overlying sediments, suggesting that the Iron Springs laccoliths came to rest not in places determined by the law of hydrostatic equilibrium but in places determined by the competency of the restraining limestone and sandstone strata; in other words, the Iron Springs laccoliths, if their density at the time of the intrusion was that common to acidic intrusives of this type, would have been intruded more nearly at the surface had it **not** been for the strength of the restraining limestone.

PETROGRAPHY.

The intrusive andesite is the rock with which the iron-ore deposits are associated. Deposits are found on the borders of all the andesite areas except Stoddard Mountain, where its absence is probably due to the absence of limestone.

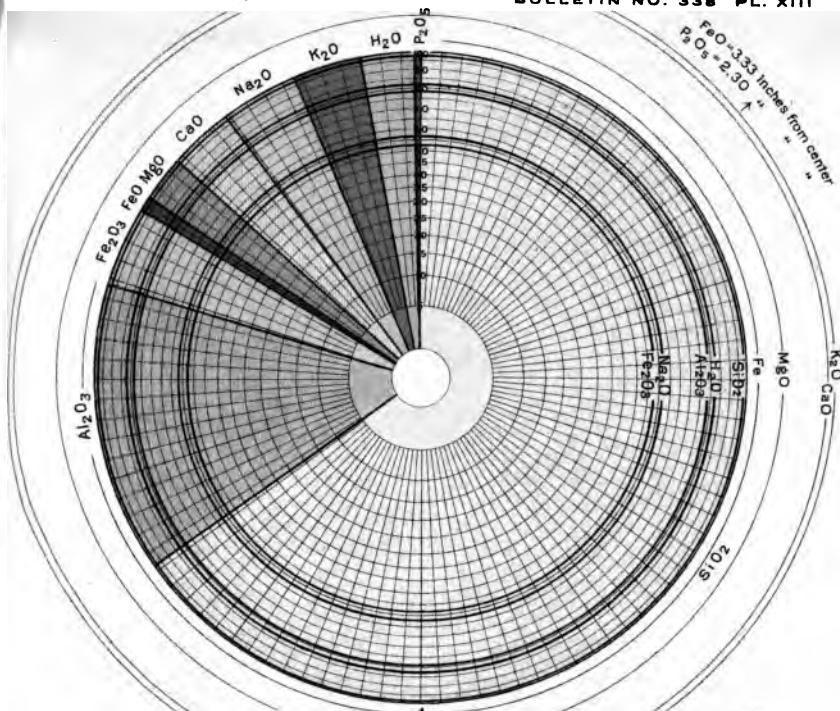
The rock is a light-gray biotite andesite with porphyritic texture. The phenocrysts, consisting of feldspar, biotite, hornblende, and diopside, are numerous, occupying more than half of the rock mass, and varying in size up to an eighth of an inch in diameter. The most abundant phenocryst is plagioclase of the variety labradorite, but orthoclase is occasionally present. A large number of feldspar show zonal growth. They are comparatively fresh, showing alteration only along cracks, along lines of zonal growth, and on the surface. The alteration products are calcite, kaolin, quartz, and sericite, typical katamorphic products. The next most abundant phenocryst is biotite, in shiny black hexagonal plates, often altered to phlogopite with a golden luster and frequently having reaction rims of magnetite. In the Stoddard Mountain area and parts of the other areas, the biotite is almost entirely decomposed to ferrite. In a few cases it has altered to green chlorite. The biotite has abundant inclusions, mainly apatite but sometimes quartz, magnetite and zircon. The hornblende is generally in dark-green prismatic crystals, with inclusions of magnetite, biotite, and quartz. Like the biotite, the hornblende in the andesite of the Stoddard Mountain area is almost entirely decomposed to ferrite. The diopside is of a light-green color, and is noticeably associated with magnetite, which is present as inclusions and around the borders. It is generally more or less altered to uralite along cracks and around the borders. Fragments of magnetite are abundant throughout the rock. Ferrite is present as an alteration product of the ferrous silicates.

The groundmass is cloudy from alteration, but seems to be composed mainly of fine crystalline quartz and feldspar, both orthoclase and plagioclase. Biotite, hornblende, pyroxine, and magnetite are also represented, but less abundantly.

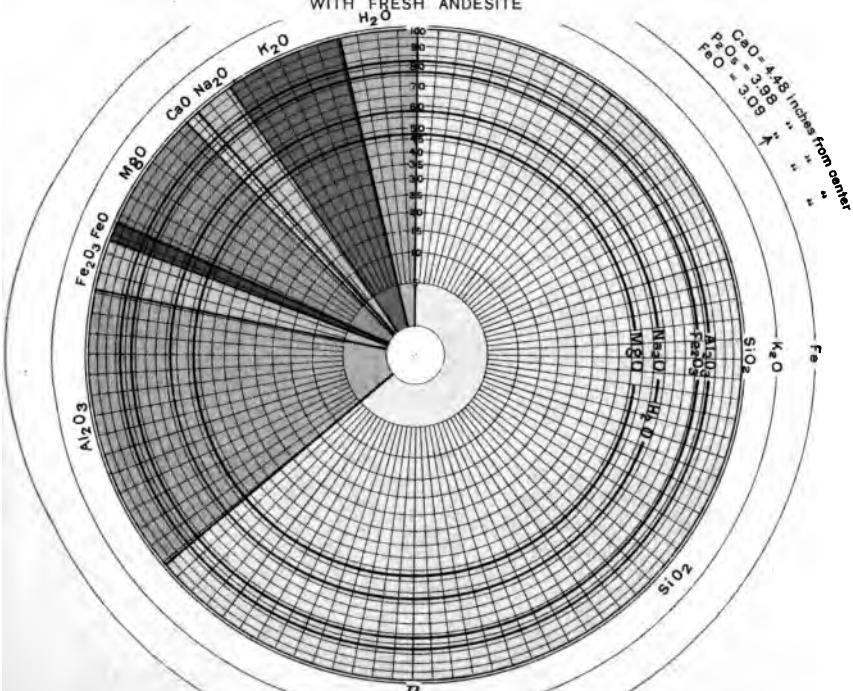
GEOLoGICAL SURVEY

BULLETIN NO. 338 PL. XIII

~~40~~ ~~MAP OF FEDERAL SURVEYS, DISTRICT, UTAH.~~



GRAPHIC COMPARISON OF COMPOSITION OF ALTERED ANDESITE, ANALYSIS "C,"
WITH FRESH ANDESITE



GRAPHIC COMPARISON OF COMPOSITION OF ALTERED ANDESITE, ANALYSIS "D,"
WITH FRESH ANDESITE

The biotite andesite has the same texture and mineral composition throughout the different areas. The absence of marginal facies (as a basic edge), dikes, and pegmatic veins is especially noticeable.

METAMORPHISM OF ANDESITE BY THE ORE-BEARING SOLUTIONS.

Near its contact with the ores for a few feet the andesite takes on a greenish-yellow color and dense texture, very similar to that of the silicated limestone at the andesite contact. The two are with great difficulty discriminated. The grain of the contact phase is much finer than that of the main mass of the andesite. The groundmass consists of finely crystalline feldspar and quartz, principally the former; cloudy with dark clayey-looking material, much of it not recognizable, but some of it in the larger masses clearly muscovite and rarely chlorite. The contact between the altered phase and the fresh andesite is sharp.

A comparison of the analyses of the fresh and contact phases by the circular-diagram method (Pls. XIII and XIV) brings out clearly the fact that at the contact the conspicuous change has been the introduction of soda. All other constituents show a possible loss, though ferric iron has developed at the expense of ferrous iron. In the present state of development of the district it is not possible to secure specimens from horizons surely below the influence of weathering. It may be that the oxidation of the ferrous iron here indicated is really a superposed weathering effect.

When the normal weathered andesite from the surface is compared with the fresh andesite, as in the following table (see also Pl. XII, B, p. 30), the change is found to be of quite a different character from that along the ore contacts. All constituents, including soda, show a loss relative to the alumina, as in Pl. XII, B.

Analyses of fresh and altered andesites.

[Analyst, R. D. Hall, University of Wisconsin.]

	A.	B.	C.	D.	E.
SiO ₂	65.29	63.63	65.80	63.82	63.76
Al ₂ O ₃	11.57	15.64	14.48	14.28	16.05
Fe ₂ O ₃	2.10	3.59	3.96	2.72	1.91
FeO.....	2.67	.93	.70	.81	.58
MgO.....	2.87	2.32	2.35	5.98	2.46
CaO.....	4.85	4.46	3.19	.70	4.25
Na ₂ O.....	2.10	1.70	3.78	3.62	6.26
K ₂ O.....	5.18	5.22	3.32	4.24	2.84
H ₂ O.....	.50	.40	.12	2.30	1.22
H ₂ O+.....	1.82	1.70	2.71	1.68	.93
P ₂ O ₅.....	.22	.15	.12	.04	.28
BaO.....	.17	.05	.06	.04	None.
	99.34	99.79	100.59	100.23	100.54

- A. Specimen 4612. Fresh andesite east of Granite Mountains.
- B. Specimen 46377. Weathered andesite from Desert Mound.
- C. Specimen 46433. Altered andesite near iron-ore contact from Blowout, south of Iron Mountain.
- D. Same nearer iron ore contact.
- E. Specimen 46481. Altered andesite near iron-ore contact from Emma claim on east slope of Iron Mountain.

EFFUSIVES (LATE MIocene).

DISTRIBUTION AND STRUCTURE.

The effusives occupy two main areas in the district—the Antelope Range area and the Swett Hills, Eightmile Hills, and Harmony Mountains area. There are small exposures at Upper Point, in the northeastern quarter, and northwest of Iron Mountain.

There is a succession of 9 flows in the following order:

<i>Succession of lava flows in Iron Springs district.</i>		Feet.
9.	Biotite-hornblende-pyroxene andesite.....	200
8.	Late tuffaceous rhyolite (Antelope Range).....	400
7.	Biotite dacite.....	300
6.	Pyroxene andesite agglomerate and breccia.....	100
5.	Latest trachyte.....	150-300
4.	Hornblende andesite breccia and agglomerate.....	150
3.	Later trachyte.....	50
2.	Early tuffaceous rhyolite.....	300-400
1.	Early trachyte.....	50-600

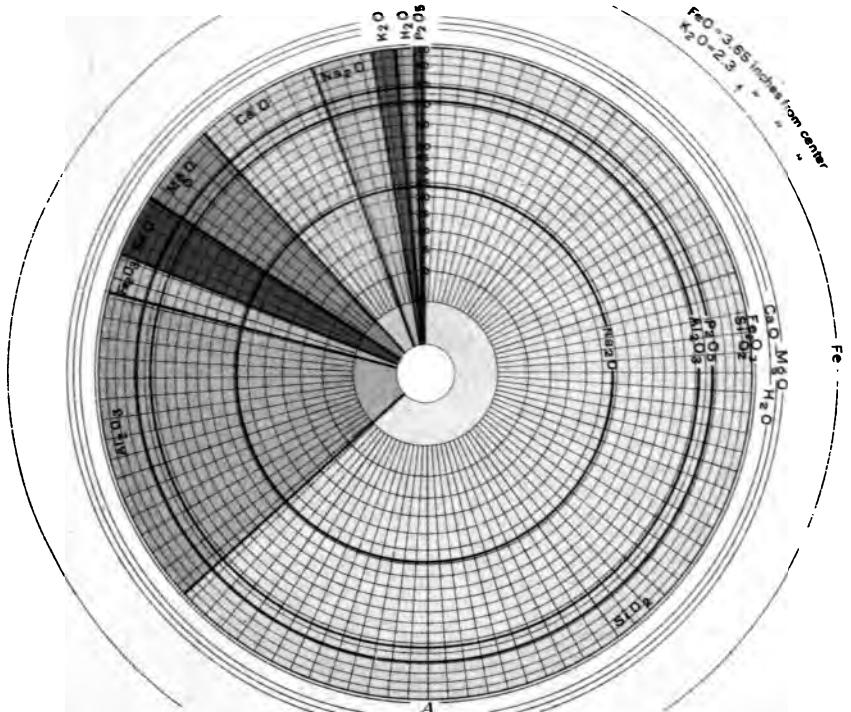
Of these Nos. 1, 2, 5, and 7, extend throughout the area and for a number of miles to the south and west, while the rest are present only in parts of the district. There is little evidence of erosion between the successive flows, unless the absence of certain beds in different places be taken as such. The oldest formation forms the border of the lava series and inside of this successively younger flows outcrop, the latest in the center. Local faulting and sheets of outwash deposits have somewhat obscured these relations in places.

The Antelope Range lavas occupy a broad syncline pitching to the northeast, while those of the Swett Hills and Harmony Mountains have a general eastward dip and are not folded.

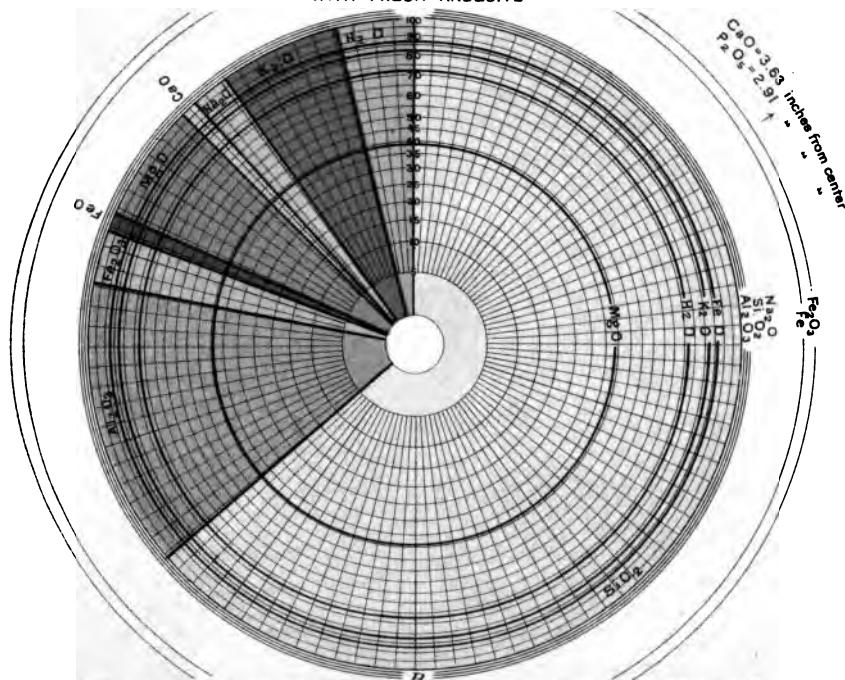
PETROGRAPHY.

Early trachyte.—The rocks of the early trachyte bed differ considerably in texture in different parts of the district as well as in different parts of the series. The color and mineralogical character, however, remain the same throughout the district. In general the rocks are dark and dense with few phenocrysts, principally feldspar, subordinately biotite.

In the Antelope Range, where it is typically exposed, the main part of the formation is a dense dark-red or purple porphyritic trachyte with very few phenocrysts. The phenocrysts are mainly orthoclase, and to a less extent plagioclase, of the variety andesine-labradorite. Both feldspars show Carlsbad twinning. They are altered along cracks and on the borders to quartz and calcite. The groundmass is dense, and in some layers contains amygdules, which are partly or



GRAPHIC COMPARISON OF COMPOSITION OF ALTERED ANDESITE, ANALYSIS "E,"
WITH FRESH ANDESITE



GRAPHIC COMPARISON OF COMPOSITION OF ALTERED ANDESITE, ANALYSIS "D,"
WITH ALTERED ANDESITE, ANALYSIS "C"

entirely filled with quartz and chalcedony. Near its base the trachyte in places becomes ferruginous, yielding from 6 to 7 per cent of iron.

The upper 30 feet of the bed has a somewhat varying character in the Antelope Range area, being composed of a main layer of lavender-gray trachyte, with thin layers of tuffaceous, scoriaceous, and dense trachytes, and has been mapped separately as far as it could be distinctly traced.

In the Swett Hills the early trachyte bed is dark gray and the phenocrysts are few. In the Eightmile Hills it is red, with numerous phenocrysts of sanidine and plagioclase and fewer of biotite. East of the Eightmile Hills and in the Harmony Mountains parts of the bed are porous and even scoriaceous, and have a predominance of lime-soda feldspar over orthoclase. In Cottonwood Canyon and westward it is complicated by additional beds of rhyolite, trachyte, and andesite similar to some of the overlying lavas. South of Iron Mountain the bed is amygdaloidal. The amygdules are spherical or oblong in shape, varying from 5 to 50 millimeters in diameter, and are filled with quartz and calcite.

Early tuffaceous rhyolite.—In the northeast and in the southern part of the Antelope Range area the early tuffaceous rhyolite bed is of uniform character throughout its vertical extent. It is a light-gray, pink, or white porphyritic rock with numerous phenocrysts, and small irregular fragments of other volcanic rocks. The phenocrysts are mainly quartz, orthoclase, and plagioclase, with less abundant biotite and hornblende. Zonal structure, secondary enlargement, and inclusions of long narrow crystals of apatite are common. The biotite is largely altered to phlogopite and is frequently associated with magnetite. Pyroxene appears in the included rock fragments, but not in the rhyolite itself. The groundmass is amorphous, except for small crystals of quartz and feldspar and cavities which are partly or wholly filled with chalcedony or calcite.

The early rhyolite bed in and near the Antelope Range in the western part of the Antelope Range area differs somewhat from the above. The succession, beginning at the bottom, is (1) a few feet of gray or black rhyolitic pitchstone, with numerous phenocrysts of quartz, feldspar, and mica; (2) hard red rhyolite which grades up into (3) a light-red rhyolite with numerous fragments of other volcanic rocks. (2) and (3) grade laterally into the tuffaceous phase of the eastern part of the area, but (1) does not change its character and is found in the same position, viz., at the bottom of the early rhyolite series, throughout this area as well as in other parts of the quadrangle. The minerals in these 3 phases are very much the same as in the tuffaceous phase, except that little or no hornblende is present. The feldspars are mainly orthoclase, but plagioclase is fairly abundant. They are altered to calcite, kaolin, and quartz, the plagioclase more

so than orthoclase. Quartz shows strong resorption, but is otherwise fresh and limpid. Under the high power, it shows inclusions. The biotite is black and shiny and has inclusions of apatite. Magnetite and ferrite are present in small quantities, the latter as an alteration product of the ferrous silicates. Zircon is rare. The groundmass is partly crystalline and partly eutaxitic and amorphous. The crystalline part appears to be mostly quartz and feldspar. There are numerous chalcedony-filled cavities throughout the rock.

The band of early rhyolite along the northwestern front of Swett Hills is bright pink with phenocrysts of quartz and sanidine, the latter with Carlsbad twinning. Both quartz and feldspar are fresh and glassy. The former frequently shows resorption. The groundmass is pink and dense, but with numerous little cavities. It appears to be amorphous with lenses of lighter colored crystalline material.

The areas of lower rhyolite in the Eightmile Hills and the Harmony Mountains, like those first described, are more or less tuffaceous in character, but as the groundmass becomes denser they grade into a fragmental rhyolite. The little neck of the early rhyolite bed west of Stoddard Canyon has a number of areas of trachyte and dacite very much like those in the purple trachyte east of Birch Canyon. These are very irregular in extent and distribution and could not be structurally so separated as to correlate them with the overlying trachyte and dacite.

Later trachyte.—Wherever the later trachyte is present it is composed of 2 distinct layers—at the base a black trachytic pitchstone averaging 5 to 10 feet in thickness and above this a dense red trachyte.

The pitchstone contains abundant phenocrysts of feldspar, biotite, and fewer of diopside, hornblende, magnetite, and apatite. The feldspars are largely sanidine, showing Carlsbad twinning, but little plagioclase is present. The feldspars are all fresh and unaltered and have numerous inclusions of apatite and zircon. The biotite is dark brown and strongly pleochroic. It has few inclusions which are mainly zircon. Magnetite fragments are abundant, some of them showing alteration to hematite. Hornblende is rare.

The groundmass is black and glassy and under the high power appears to be made up of innumerable crystallites with simple branching hairlike forms grouped along lines of flow. In it are spherulites, some of which in addition to the spherulitic structure show flow structure like the rest of the groundmass.

The trachyte above the pitchstone is a reddish-brown porphyritic rock with phenocrysts of feldspar and biotite, about equally abundant, and together making up perhaps one-tenth of the mass of the rock. Both orthoclase and plagioclase are present, the latter being prob-

PL. II

113°10'
37°47'30"

LEGEND

REDACTED

a little more abundant. They are very much altered to a white clayey material, probably kaolin. The biotite is fresh, dark brown, and strongly pleochroic. It has a few inclusions of apatite. Magnetite particles are numerous. The groundmass is cloudy from specks of ferrite and shows flow structure, especially around the phenocrysts. It appears to be partly amorphous with tiny specks of feldspar arranged along flow lines. The phenocrysts are also arranged parallel to the lines of flow.

Hornblende andesite breccia and agglomerate.—In the western and northern parts of the Antelope Range area the hornblende andesite is a greenish-gray breccia, but toward the south it grades into a coarse agglomerate, with dark-gray and black fragments. In the breccia the fragments are of dark andesite and rather small, the largest being about 10 inches in diameter, and by far the larger part being smaller. The material between the fragments is of the same character as the fragments but somewhat softer. In the agglomerate the fragments are larger, ranging up to perhaps 2 feet in diameter. Most of them are composed of the same material as the fragments of the breccia, but other fragments are red and trachytic. The intervening material in the agglomerate is light gray and tuffaceous and weathers readily, leaving the fragments strewn around over the surface like boulders. These soon become black and shiny from desert varnish.

The hornblende andesite composing the fragments is a dark-gray porphyritic rock stained green in many places. The main phenocrysts are narrow crystals of hornblende, sometimes one-fourth inch long. A few phenocrysts of feldspar are present. The groundmass is dark gray and finely crystalline and makes up about nineteen-twentieths of the rock mass. The hornblende has a dark-brown color and shows pleochroism. Fragments of magnetite are found bordering it and included in it, but generally separated from it by an alteration rim of ferrite. The hornblende is altered to ferrite on the surface and sometimes well into the interior.

The ground mass is composed largely of small crystals of orthoclase and plagioclase of the variety labradorite, the latter being a little more abundant. Besides the feldspar, pyroxene, hornblende, and magnetite occur in the groundmass. The small crystals are separated by areas of cryptocrystalline material.

Latest trachyte.—The latest trachyte bed is easily recognized throughout its extent by a characteristic banded appearance. It is composed of several different layers; the full section, which is present only in the eastern part of the Antelope Range area, is as follows, beginning at the base: (1) a few feet of black trachytic pitchstone with phenocrysts mainly sanidine, but with plagioclase, biotite, and

diopside present; (2) red trachyte with grayish-white bands; (3) gray and red trachytes, slightly banded in places; (4) gray tuffaceous trachyte; (5) hard, dense red trachyte. These phases differ only in texture, the phenocrysts (mainly sanidine, subordinately plagioclase, biotite, and magnetite) being the same throughout the series with the exception that layer 5 contains a few pyroxenes, and biotite and magnetite are slightly more abundant than in the other layers. There is also a slight variation in the amount of plagioclase in different parts of the latest trachyte bed.

Outside of the eastern Antelope Range area only layers 1 and 2 and perhaps 3 are present. In the eastern part of the Antelope Range area layer 2 is comparatively thin, but throughout the rest of the quadrangle it forms almost the entire thickness of the bed, although the banding is not always as conspicuous as it is here. The black pitchstone is nearly always present at its base. At the top of the bed in other parts of the quadrangle there is often a layer of less distinctly banded material which may represent layer 3. The absence of the upper layers is probably due to nondeposition, since erosion could hardly have taken place so uniformly over the region as to leave practically the same thickness of trachyte throughout.

The latest trachyte of the Antelope Range (layer 2) is a reddish porphyritic rock, with parallel bands of white and gray material averaging generally less than one-eighth inch in thickness. The phenocrysts, averaging about one-sixteenth of an inch in diameter, form about one-tenth of the rock and are largely sanidine. At the surface these have been entirely leached out, leaving only the cavities. Biotite is also present, being generally altered to phlogopite and often entirely decomposed to ferrite. Phenocrysts appear to be present in both the gray and red bands. Nearly all the sanidine shows Carlsbad twinning. In general, they appear to be quite fresh, showing alteration only on the surface and along fractures. The alteration products appear to be calcite, kaolin, and quartz. The sanidine frequently has inclusions of zircon and apatite. A little plagioclase, variety andesine, is present. Magnetite occurs as fragments.

The red part of the groundmass shows flow structure and is more cloudy than the gray part, owing to numerous little specks of ferrite. It is amorphous for the most part, with here and there specks of feldspar. The gray part appears to be impregnated with quartz. It contains elongated quartz-filled cavities which grade into the more cloudy quartz-impregnated groundmass. In the center of some of the larger cavities there are brownish aggregates of fine cryptocrystalline material. These silicious fillings are probably later than the rest of the rock, having been deposited in the porous parts. This

view is strengthened by the fact that the banded appearance of this formation in other parts of the district is caused by a difference in the character of the ground mass, the lighter bands being porous and the darker ones more dense.

The rocks of the latest trachyte bed over other parts of the district are very similar to the one described above with regard to mineral composition and texture, except for the lesser abundance of quartz in the lighter colored bands.

Pyroxene andesite agglomerate and breccia.—In the western part of the Antelope Range area the pyroxene andesite bed is a greenish-gray copper-stained breccia, with little or no difference between fragments and groundmass. Toward the east it grades into a coarse agglomerate with huge dark boulder-like fragments, cemented by gray tuffaceous material. This agglomerate is very much like the hornblende andesite agglomerate, but as a general rule it has larger fragments.

The rock composing the fragments in the breccia and agglomerate is a pyroxene andesite. It is dark gray in color and has porphyritic texture, the phenocrysts making up perhaps one-tenth of the rock and averaging one-eighth inch in diameter. The phenocrysts are pyroxene and plagioclase, variety labradorite, the former being the more abundant. The groundmass is dense and appears to be composed of minute crystals. The pyroxene is light green in color, shows a slight brownish pleochroism, and has included magnetite fragments. Often it occurs in aggregates of 2 or 3 and sometimes shows twinning parallel to the orthopinacoid (100). Plagioclase is not very abundant, and has suffered considerable alteration to calcite and kaolin. It shows zonal structure and, like the pyroxene, occurs in aggregates.

The groundmass is composed of numerous crystals of plagioclase and fewer of orthoclase, pyroxene, and magnetite, separated by amorphous areas.

Biotite dacite.—The biotite dacite has the same texture and mineral composition throughout both its vertical and horizontal extent. The color, however, varies slightly. In the Antelope Range area the main part has a reddish-brown color, while at the base there are 50 feet or less of a pinkish-gray color. Outside of the Antelope Range area the latter makes up the entire formation.

The biotite dacite is a porphyritic rock with phenocrysts ranging up to one-eighth inch in diameter and making up fully half of the rock mass. They are mainly feldspar and biotite, subordinately diopside, quartz, and brown hornblende. The feldspars are mainly plagioclase, ranging from basic andesine through labradorite to acidic bytownite. Orthoclase is also present, but not as abundant. A large number of the feldspars show well-developed zonal structure,

the successive zones of growth being very thin, owing to rapidly alternating conditions in the formation of the crystal. There is considerable alteration along fracture lines, the most important decomposition product being calcite. The feldspars have inclusions of apatite and biotite. The biotite is dark brown and greenish brown, highly pleochroic, and has inclusions of feldspar. The diopside is light green in color and has numerous inclusions of magnetite. It is often very much decomposed, the products being calcite and ferrite. Fragments of quartz, which frequently show resorption, are present. The hornblende is of the brown basaltic variety. Fragments of magnetite are abundant.

The groundmass is amorphous and frequently shows flow structure. Through it are scattered tiny specks of the same minerals as compose the phenocrysts.

Late tuffaceous rhyolite.—The late tuffaceous rhyolite has the same character throughout, except for an agglomerate at the base. The latter consists of big boulders and smaller fragments of dark igneous material, both acidic and basic. About halfway up in the tuff formation there is, in a few places, a thin layer of coarse sandy material, which appears to be water deposited. Frequently the upper part of the formation contains numerous concretion-like spheres, ranging from 1 inch to 5 inches in diameter, which are very much harder and darker than the rest of the rock. These have the same minerals as the rest of the formation, but the groundmass is denser and the cavities have all been filled with chalcedony.

The late tuffaceous rhyolite has a porphyritic texture with phenocrysts of feldspar, quartz, biotite, and hornblende, and a porous glassy groundmass. The main phenocryst is quartz, which is very fresh and generally shows crystal outlines. Orthoclase and plagioclase are present, but not abundant. Most of them have suffered surface alteration. The biotite is frequently twinned and has inclusions of apatite. Fragments of hornblende and pyroxene are present, the latter being in included rock fragments. Magnetite particles are scattered through the rock.

The groundmass is amorphous with numerous cavities filled or lined with calcite. For this reason calcite forms quite a large percentage of the rock.

Biotite-hornblende-pyroxene andesite.—In the Swett Hills the biotite-hornblende-pyroxene andesite bed consists of several types of rock. In the western part there is at the base a dark hornblende andesite breccia and above this several layers of rhyolite and trachyte interlayered with limestone and conglomerate. In the eastern part all but the breccia disappear, and a biotite-hornblende-pyroxene andesite, which to the west only caps the lower series, makes up

almost the entire thickness. In the Harmony Mountains the formation consists of rhyolite, trachyte, and conglomerate, while in the lava area southwest of Iron Mountain only the hornblende andesite breccia is present, with a little limestone and conglomerate.

The biotite-hornblende-pyroxene andesite is a light pinkish-gray porphyritic rock, with feldspar as the main phenocryst. Biotite, hornblende, and diopside are of equal importance. Quartz and magnetite are present. The feldspars are mainly labradorite, but a little orthoclase is present. They show zonal growth and have inclusions of apatite. A few fragments of quartz are present. The diopside is light green in color, while the hornblende and biotite are dark brown and show alteration to ferrite. The groundmass is amorphous with finely crystalline feldspar and specks of ferrite.

The hornblende andesite breccia is a dark purplish-gray porphyritic rock, with phenocrysts of brown hornblende and a groundmass of small lath-shaped crystals of labradorite, orthoclase, monoclinic and rhombic pyroxene, separated by irregular cavities. The rhyolite and trachyte layers have the same texture as the underlying tuffaceous rhyolite and trachyte formations. The limestones and conglomerate are like those of the Tertiary, but thinner and less consolidated. Their presence in the uppermost lava formation shows that all the lavas were submerged after its deposition.

CHEMICAL AND MINERAL COMPOSITION OF THE IGNEOUS ROCKS.

Analyses have been made of the intrusive andesite and of the four principal flows, namely, the early trachyte (1), early rhyolite (2), latest trachyte (5), and dacite (7). Of the rest of the flows, some, while they have considerable horizontal distribution, are very thin, while the others are local in their distribution.

The following table gives the chemical composition, the approximate mineral composition of the same specimens determined from thin sections, and the mineral composition of the same specimens calculated as modes from the chemical composition for each of these formations, in order of age:

Analyses of igneous rocks from Iron Springs district.

CHEMICAL COMPOSITION.

	A.	B.	C.	D.	E.	E'.	F.	G.
SiO ₂	65.29	63.63	64.83	58.04	66.38	70.03	73.17	61.05
Al ₂ O ₃	11.57	15.64	16.68	18.96	13.72	14.47	13.34	16.03
Fe ₂ O ₃	2.10	3.59	3.74	5.88	2.23	2.35	1.35	5.42
FeO.....	2.67	.93	1.22	1.33	.80	.84	.76	.98
MgO.....	2.87	2.32	.79	1.11	.54	.57	.81	3.03
CaO.....	4.85	4.46	2.85	6.12	5.49	2.42	1.32	5.40
Na ₂ O.....	2.10	1.70	.86	2.26	2.50	2.64	1.80	1.43
K ₂ O.....	5.18	5.22	7.56	4.08	5.20	5.48	7.10	5.58
H ₂ O+.....	2.32	2.10	.92	2.05	.92	.97	.54	.81
P ₂ O ₅.....	.22	.15	.35	.34	.08	.08	.07	.30
CO ₂					2.52			
BaO.....	.17	.05	.11	.04	.11	.11	.10	.08
	99.34	99.79	99.91	100.21	100.49	99.96	100.36	100.11

MINERAL COMPOSITION DETERMINED FROM THIN SECTIONS.

	A.	B.	C.	D.	E.	F.	G.
Quartz.....	Some	Some	Some	Some	Much	Some	Some
Orthoclase.....	Some	Some	Some	Some	Much	Some	Much
Plagioclase.....	Much	Much	Little	Much	Little	Little	Much
Biotite.....	Some	Some	Little	Little	Some	Some	Some
Hornblende.....	Some	Little	Little	Little	Some	Some	Some
Diopside.....	Little	Little	Little	Little	Little	Little	Some
Magnetite.....	Little	Little	Little	Little	Little	Little	Little

MINERAL COMPOSITION CALCULATED FROM CHEMICAL COMPOSITION.

	A.	B.	C.	D.	E.	F.	G.
Quartz.....	23.52	22.26	22.02	15.06	27.60	33.12	19.38
Orthoclase.....	28.35	27.80	43.37	22.79	28.35	39.47	28.35
Albite.....	14.67	13.10	7.34	18.86	20.96	15.19	12.05
Anorthite.....	5.84	15.29	11.12	25.85	10.56	5.56	15.84
Biotite ^a	5.08	4.63	3.81	3.71	3.70	2.70	2.70
Phlogopite ^a						1.62	4.16
Hornblende ^a	5.89	1.99					
Diopside.....	6.03	4.32	.86	2.16			7.12
Magnetite.....	1.39	1.16	1.85	2.78	1.62	.92	1.85
Apatite.....	.31	.31	.62	.62	.31	.31	.62
Limonite.....		2.24	.75	4.11	.56	.75	.75
Hematite.....			1.28				3.52
Calcite.....					5.70		
Kaolin.....		3.78	5.16	3.09			3.61
Serpentine.....	2.48	1.84					
Water.....	1.90	.90		.97	.76	.34	
Sillimanite.....			1.45				
Wollastonite.....	3.48						
	98.94	99.62	99.63	100.00	100.12	99.98	99.95

^a Composition based on average of analyses in Dana's Manual of Mineralogy.

A. Specimen 46612. Fresh intrusive andesite east of Granite Mountain. Analysis by R. D. Hall, University of Wisconsin.

B. Specimen 46377. Slightly weathered intrusive andesite from Desert Mound. Analysis by R. D. Hall, University of Wisconsin.

C. Specimen 46533. Fresh early trachyte from Antelope Range (No. 1 of flows). Analysis by R. D. Hall, University of Wisconsin.

D. Specimen 46584. Andesite from same formation as specimen C north of Stoddard Mountain. Analysis by R. D. Hall, University of Wisconsin.

E. Specimen 46521. Early rhyolite from Eightmile Hills (No. 2 of flows). Analysis by R. D. Hall, University of Wisconsin.

E'. Specimen 46521. Early rhyolite. Recalculated on the basis of 100 per cent after removing CaO and CO₂ of the infiltrated calcite.

F. Specimen 46557. Latest trachyte from Antelope Hills (No. 5 of flows). Analysis by R. D. Hall, University of Wisconsin.

G. Specimen 46586A. Dacite from Swett Hills (No. 7 of flows). Analysis by R. D. Hall, University of Wisconsin.

Partial chemical analyses of igneous rocks from Iron Springs district.

[Analyst, Fred Lerch, Biwabik, Minnesota.]

	H.	I.	J.	K.	L.	M.	N.
SiO ₂	53.65	66.20	...	...	...	...	...
Al ₂ O ₃	1.59	2.72	...	...	...	...	...
P ₂ O ₅.....	.118	.117	...	.076	.138	...	...
Fe.....	5.65	3.71	4.56	5.58	6.49	4.91	5.16
	O.	P.	Q.	R.	S.	T.	U.
P ₂ O ₅.....	.133	.060	.074	.040	.032	.124	.127
Fe.....	5.79	2.43	2.29	2.78	1.74	4.03	4.24

II. Specimen 46317. Intrusive andesite. Three Peaks.
 I. Specimen 46318. Same.
 J. Specimen 46500. Early trachyte. Eightmile Hills.
 K. Specimen 46533. Same. Antelope Range.
 L. Specimen 46540. Same.
 M. Specimen 46541. Same.
 N. Specimen 46547. Same.
 O. Specimen 46584. Same. North of Stoddard Mountain.

P. Specimen 46502. Early tuffaceous rhyolite. Eightmile Hills.
 Q. Specimen 46503. Same.
 R. Specimen 46476. Latest trachyte. Swett Hills.
 S. Specimen 46477. Same (pitchstone at base).
 T. Specimen 46504. Biotite dacite. Eightmile Hills.
 U. Specimen 46380. Same.

Analyses A and B are average andesites, although A is a little too high in potash and low in alumina. C is a typical trachyte, while D is an andesite forming a subordinate part of the early trachyte bed.

The early rhyolite (E) is too high in lime, owing to secondary calcite occurring in amygdules. This has been subtracted from the analysis and the latter recalculated to 100 per cent. This recalculated composition (E') is that of a typical rhyolite. The composition of F, as given in the table, is too high in silica and too low in alumina for a trachyte. The excess silica is accounted for by secondary infiltration in amygdules, and if this be removed and the composition recalculated to 100 per cent the alumina percentage will be brought up within the limits. The lack of quartz phenocrysts determines its name.

The dacite (G) is too low in silica for a typical dacite, but the presence of quartz phenocrysts determines its name.

According to Professor Iddings the presence of trachyte and andesite in the same group of lavas is a rare occurrence, nevertheless chemical and mineral compositions indicate that both probably occur in the Iron Springs area.

The analyses represent the general acidic character of the series and show a slight range in chemical composition, especially in the silica and alkalies. Silica ranges from 58 to 70 per cent, the increase to 73 per cent in analysis F being due largely to the later cavity fillings. The alkalies range from 6½ to 9 per cent, the potash being in excess of the soda in all cases. This excess reaches a maximum in the trachytes C and F, a fact well illustrated in the mineral composition

tables by the excess of potash feldspar over lime-soda feldspar in these rocks.

The alkalis vary approximately with the amount of silica, as follows:

Variations in alkali and silica in igneous rocks of Iron Springs district.

	F.	E.	A.	C.	B.	G.	D.
SiO ₂	73.17	70.03	65.29	64.83	63.63	61.05	58.04
Alkalies.....	8.90	8.12	7.28	8.42	6.92	7.01	6.34

The only striking exception to this rule is "C," which is high in alkalis and comparatively low in silica.

The total alkalis vary inversely as the lime with minor exceptions.

Variations in alkali and lime in igneous rocks of Iron Springs district.

	F.	C.	E.	A.	G.	B.	D.
Alkalies.....	8.90	8.42	8.12	7.28	7.01	6.92	6.34
CaO.....	1.32	2.85	2.42	4.85	5.40	4.46	6.12

An increase in the amount of silica and alumina is attended by a decrease in iron, magnesia, and lime, illustrated in the following table:

Variations in silica and alumina corresponding to variations in iron, magnesia, and lime in igneous rocks of Iron Springs district.

	F.	E.	C.	B.	G.	D.	A.
SiO ₂ and Al ₂ O ₃	86.51	84.50	81.51	79.27	77.08	77.00	76.86
Fe ₂ O ₃ , FeO, MgO, and CaO.....	4.24	6.18	8.60	12.30	14.83	14.94	12.49

The relation between the potash and soda is similar to that shown by Professor Pirsson to exist in the rocks of the Highwood Mountains,^a but the relation between the alkalis and the lime is reversed. The definite relation existing between potash, soda, and lime in the Highwood rocks, according to Professor Pirsson, must have been characteristic of the parent magna, and separates these rocks from rocks of other areas and groups them into a clan. The same argument may be applied to the rocks of the Iron Springs district.

The chemical character of the rocks is clearly expressed by the mineral composition. The predominance of potash is indicated by an abundance of orthoclase, while the basic feldspar varies in amount with the lime, except in the early rhyolite (E), in which the high

^a Pirsson, L. V., Petrography and geology of the igneous rocks of the Highwood Mountains, Montana: Bull. U. S. Geol. Survey No. 237, 1905, pp. 172-174.

lime percentage is accounted for by the presence of infiltrated calcite. In analyses C, D, E, and F the low magnesia explains the absence of hornblende and diopside and the lowering of the biotite percentage.

The mineral compositions calculated from the analyses (p. 58) are in general similar to those observed, yet on account of fine-grained or amorphous groundmass the mineral composition as determined from thin sections could only be approximate and in some instances does not correspond well with the calculated modes, the greatest discrepancy being in the relative amounts of quartz, orthoclase, and lime-soda feldspar. Where the groundmass is cryptocrystalline, the mineral composition is based on the phenocrysts. In the dacite and andesites these form a large percentage of the mass of the rock, while in the early trachytes, the early rhyolite, and the latest trachyte they are subordinate in amount. Sillimanite and wollastonite were not seen in the rocks, but were added to take up surplus alumina and lime.

RELATIONS OF LACCOLITHS AND EFFUSIVES IN GENESIS.

The question naturally arises whether or not the intrusive andesite and the effusives came from the same reservoir. The chemical compositions of the laccolithic rocks and the different flows show but a small range. With very little differentiation all the different phases may have originated from the same parent magma. It is certain, however, that the laccoliths did not act as vents through which the outpouring of the effusives took place. The andesite had been intruded, solidified, and eroded when the lavas were poured out over the eroded edges of the uplifted sediments. That the lavas came to the surface through the laccoliths after their solidification and erosion does not seem likely, since the andesite areas show no dikes or stocks, unless the ore veins be so called. Neither are there stocks or dikes elsewhere in the district through which the eruptions might have occurred; hence we are driven outside of the area for the source of the effusives.

The following table shows an approximation of the average chemical composition of the lavas and andesite, obtained by averaging the preceding analyses. The general similarity of composition indicates that both may have come from the same reservoir.

Average chemical composition of laccoliths and effusives.

	Laccoliths.	Effusives.		Laccoliths.	Effusives.
SiO ₂	64.46	66.42	K ₂ O.....	5.20	5.99
Al ₂ O ₃	13.60	15.41	H ₂ O+.....	2.21	.95
FeO.....	2.85	3.48	P ₂ O ₅.....	.18	.19
FeO.....	1.80	.96	BaO.....	.11	.09
MgO.....	2.59	1.34			
CaO.....	4.65	3.40			
Na ₂ O.....	1.90	1.86			
				99.55	100.09

CHAPTER V.

CORRELATION.

SEDIMENTARY ROCKS.

Several excursions were taken into the surrounding country for the purpose of correlating the formations of the Iron Springs district with those of the Colob Plateau, one of the High Plateaus of Utah, and with the Pine Valley Mountains.

The rocks of these areas were first studied in 1871, 1872, and 1873 by G. K. Gilbert, A. R. Marvine, and E. E. Howell for the Wheeler Survey.^a In 1875, 1876, and 1877, they were studied by Maj. C. E. Dutton^b for the Rocky Mountain Survey and again in 1880 for the United States Geological Survey in connection with the work in Grand Canyon. In the summer of 1902 a small area east of the Pine Valley Mountains along the west margin of the High Plateaus was mapped by E. Huntington and J. W. Goldthwait,^c under the direction of Prof. W. M. Davis, of Harvard University.

Dutton^d classified the rocks of this region into systems from Carboniferous to Quaternary. Huntington and Goldthwait^e subdivided the larger division of Dutton to some extent, and applied geographic names. The following tables show the correlation of the rocks of the Iron Springs district with those given by Huntington and Goldthwait and by Dutton:

^a Gilbert, G. K., Report on the geology of portions of Nevada, Utah, California, and Arizona, examined in the years 1871 and 1872: U. S. Geog. Surv. W. 100th Mer., vol. 3, Geology, pt. 1, 1875, pp. 17-187. Marvine, A. R., Report on the geology of route from St. George, Utah, to Gila River, Arizona, examined in 1871: U. S. Geog. Surv. W. 100th Mer., vol. 3, Geology, pt. 2, 1875, pp. 189-225. Howell, E. E., Report on the geology of portions of Utah, Nevada, Arizona, and New Mexico, examined in the years 1872 and 1873: U. S. Geog. Surv. W. 100th Mer., vol. 3, Geology, pt. 3, 1875, pp. 227-301.

^b Dutton, C. E., Report on the geology of the High Plateaus of Utah: U. S. Geog. and Geol. Surv. Rocky Mtn. Region, 1880, pp. 307; Tertiary history of the Grand Canyon district: Mon. U. S. Geol. Survey, vol. 2, 1882, pp. 264.

^c Huntington, Ellsworth, and Goldthwait, J. W., The Hurricane fault in the Toquerville district, Utah: Bull. Mus. Comp. Zool., Harvard Coll., No. 42 (Geol. Ser., vol. 6), 1904, pp. 199-259.

^d Dutton, C. E., op. cit.

^e Op. cit., pp. 202-208.

Correlation of rocks of the Iron Springs district with rocks of the Colob Plateau.

Colob Plateau.		Iron Springs district.
Huntington and Goldthwait.	Dutton.	
B asalt.	Quaternary sand, gravel, and clay. Basalt.	Quaternary sand, gravel, and clay.
P leistocene gravels.		Pleistocene conglomerate.
T rachyte, andesite.	Andesite, trachyte, rhyolite.	Andesite, trachyte, rhyolite, etc.
T ertiary limestone, shale, and conglomerate.	Tertiary limestone, shale, and conglomerate.	Claron limestone, including some sandstone and conglomerate.
C retaceous sandstone, shale, and limestone.	Cretaceous sandstone, shale, and limestone.	Pinto sandstone, including some shale, conglomerate, and limestone lenses.
C olob sandstone.	Jurassic shale. Jurassic sandstone.	(?)
K anab sandstone. P ainted Desert sandstone and shale. S tinarump conglomerate.	Triassic sandstone, shale, and conglomerate.	(Missing.)
M oencopie shale and sandstone.	Permian shale and sandstone.	(Missing.)
S uper-Aubrey shale and limestone. Aubrey limestone.	Carboniferous limestone.	Homestake limestone.

The fossils found in the Homestake limestone are few and poorly preserved. They were referred for determination to Prof. Eliot Blackwelder, of the University of Wisconsin, and Dr. George H. Girty, of the United States Geological Survey. Professor Blackwelder determined some of the better preserved forms as *Aviculopecten*, a genus ranging from Silurian to Triassic, but here probably Carboniferous. Doctor Girty says:

The specific determination of these forms is hardly possible from the imperfect condition of the material. . . . I believe that should you obtain more complete collections they would prove that the beds from which they were obtained should be correlated with that portion of the Wasatch Mountains section which the geologists of the Fortieth Parallel Survey designated the Permo-Carboniferous. This is likely to be the highest Paleozoic horizon found in your region.

The overlying Pinto formation is satisfactorily determined as Cretaceous. The Homestake limestone could not be Jurassic, according to its fossils, and since the limestone is dissimilar to the Triassic and Permian sediments of the adjacent High Plateaus, which are masses of sandstone and shale, it is referred to the next preceding period, the Carboniferous. Specific correlation with the Aubrey (Carboniferous) limestone naturally suggests itself, but it differs much from the latter in appearance and lithologic character, in that it is more sandy, shows bedding plainly, and is yellow, while the Homestake limestone is a pure, massive, dark-blue-gray limestone, lacking a conspicuous bedding.

So far as known, the Pinto sandstone of the Iron Springs quadrangle bears no fossils, but in the southern part it contains a few layers of carbonaceous shales, which were followed southward and connected with the anthracite beds of Stoddard Mountain (mapped by the Wheeler Survey as Cretaceous and correlated by that survey with the Cretaceous rocks on the Colorado Plateau), which contain numerous workable seams of bituminous coal, associated with oyster beds often several feet in thickness. The lower part of the Pinto formation may be Jurassic, but no evidence for the separation could be found.

The Claron formation contains only a few fossils and these are Carboniferous forms in pebbles in the conglomerates. They are of value only in pointing to a Carboniferous limestone outside of the district as the source of the conglomerates. Nevertheless, the Claron formation may be satisfactorily correlated with the Tertiary of Dutton,^a which is the Uinta formation of Smith,^b on the Markagunt Plateau. At the head of Cedar Canyon (Coal Creek valley), cutting the Markagunt Plateau, there are 3,000 feet of many-colored Tertiary limestones, sandstones, and conglomerates. The limestone of the Cedar Canyon Tertiary and of the Claron were found to be much the same both in regard to general appearance and lithology. Both are many colored, although red predominates, and both are sandy. The cherty concretions described above are also characteristic of many layers in both areas. The Claron formation of the Iron Springs district contains more fragmental material in the form of beds of conglomerate, but this is to be expected, because it is nearer the shore line of the Eocene lake supposed by Smith to lie west of the High Plateau region. The Uinta formation is supposed to have been deposited in a fresh-water lake basin, which during the early stages of deposition extended into southwestern Utah nearly to the Nevada and Arizona boundaries but gradually retreated northeastward into central Utah. The lower part of the Cedar Canyon Tertiary was not seen. It may contain more beds of conglomerate than the middle and upper parts, and hence this part might be more specifically correlated with the Claron formation of the Iron Springs district.

In general, then, the correlation of the Cretaceous and Tertiary rocks of the Iron Springs district is based on similarity in lithology, thickness, and succession of the Pinto and Claron formations with the Cretaceous and Tertiary series, respectively, of the High Plateaus beginning 15 miles to the east, and on the direct connection of the Pinto formation with the Cretaceous coal-bearing beds of Stoddard Mountain. The assignment of the underlying Homestake formation to the Carboniferous is based on obscure fossil forms and

^a Op. cit.

^b Smith, J. H., The Eocene of North America: Jour. Geol., vol. 8, 1900, p. 452.

CORRELATION.

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on the fact that, though differing lithologically from the Aubrey limestone (Carboniferous) of the High Plateaus, it is more like it lithologically than any other formation underlying the Cretaceous of this region. A possible hiatus between the Pinto formation (Cretaceous) and the Homestake limestone (see p. 17) may account for the absence of Permian, Triassic, and perhaps Jurassic sediments—if the last named, indeed, be absent (see p. 16)—between the Cretaceous and Carboniferous of this district. The weak features of the correlation are the absence of sufficient fossil evidence, the dissimilarity of the Homestake and Aubrey formation, and the absence of Permian, Triassic, and Jurassic sediments with so slight a structural discordance.

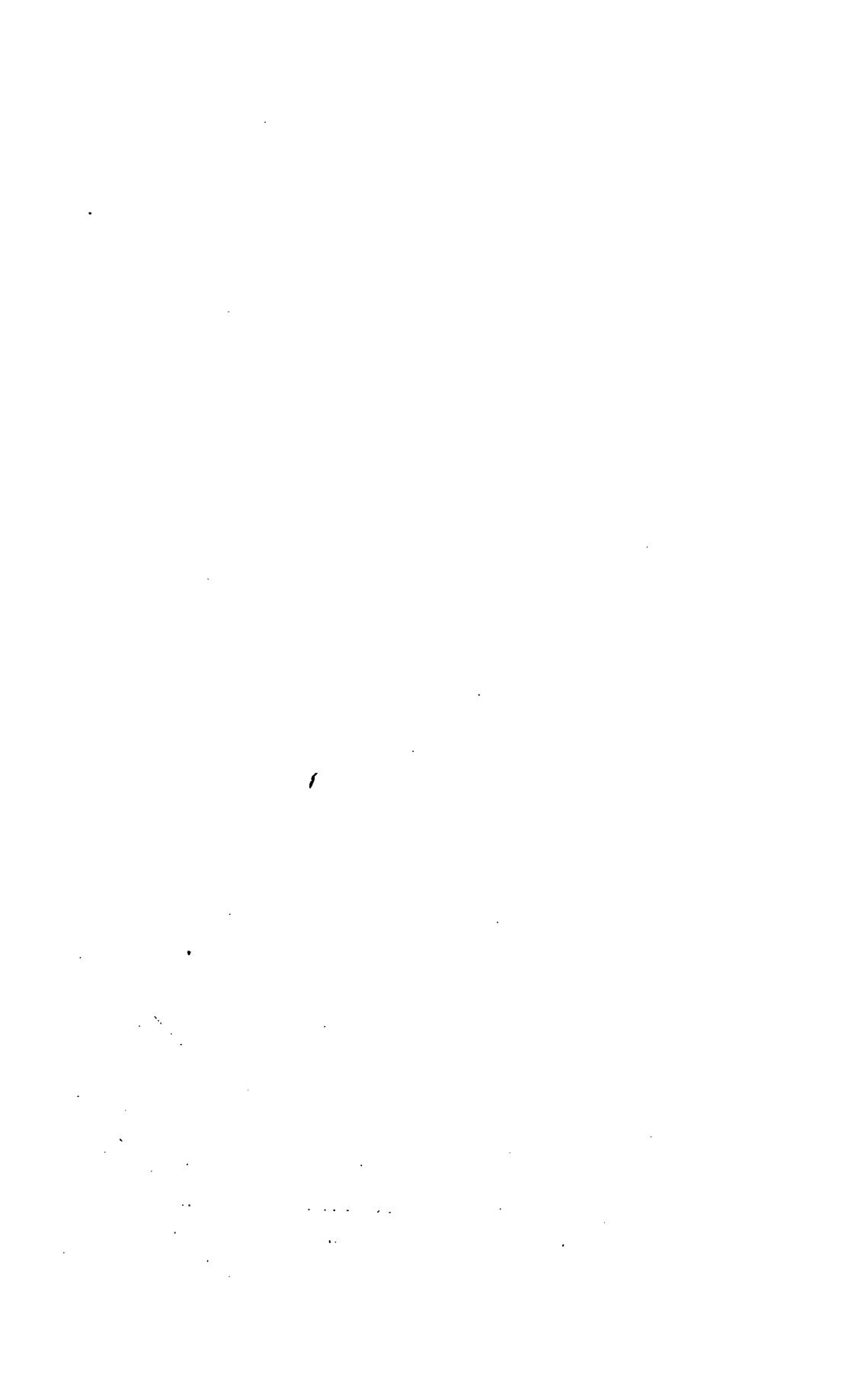
IGNEOUS ROCKS.

Only the earlier trachyte and the tuffaceous rhyolite have been correlated with rocks previously studied outside of the district, namely, the "rhyolite" of Dutton's High Plateaus survey.^a These rocks were examined on Brian Head, near the south end of the area mapped by Dutton as rhyolite, and were found to be composed of a considerable thickness of rhyolite underlain by a rather thin layer of dark scoriaceous material like some of the scoriaceous phases of the earlier trachyte of the Iron Springs district. Below this, as in the Iron Springs district, were found Tertiary limestones and conglomerates. Thus a general correlation with the lavas may be made on the basis of their superposition above the Tertiary limestones and conglomerates in the two districts.

^a Dutton, C. E., Report on the geology of the High Plateaus of Utah: U. S. Geog. and Geol. Surv. Rocky Mtn. Region, 1880, pp. 61 et seq.







ORE DEPOSITS IN ANDESITE.

The deposits within the andesite appear at the surface in long, narrow bands, ranging from 20 feet down to less than 1 foot in width, and usually standing from a few feet to 20 or 30 feet above the adjacent andesite. (Pl. XVIII, A.) These are true veins or fissure deposits. The fissures which they fill are usually somewhat curved, tapered at one or both ends, are almost invariably branching, and are accompanied by subsidiary parallel fissures. (See Pl. III.) Their orientation is diverse; in general they follow the directions of the adjacent jointing and faulting.

ORE DEPOSITS AT ANDESITE-LIMESTONE CONTACT.

The larger and more numerous deposits are along the andesite-limestone contact. (Pls. III, V, and XVII, A.) As exposed in the erosion surfaces they are commonly lens shaped, with their longer diameters parallel to the contours of the hills, but from this there are important variations toward irregular polygonal shapes, due partly to faulting and partly to the variation in the angle between the erosion surface and the plane of the andesite-limestone contact which the ores follow. The deposits at the contact have as a hanging wall either the fresh limestone or the silicated phase characteristic of the contact with the andesite. The ore protrudes irregularly into the limestone in large and small masses and veins. Small masses of the ore, measuring from a few inches to a few feet, may be seen entirely within the limestone, and in turn fragments of limestone are found in the ore. Along fault planes the limestone is brecciated and cemented by ore. Notwithstanding this local irregularity, measured by inches and a few feet, the contacts on a large scale are usually even and continuous. The dip of the contact of the ore and the hanging wall is almost invariably steeper than the dip of the bedding of limestone; that is, almost vertical but with a slight dip away from the andesite, so far as can be determined from the sections exposed.

The foot wall of the ore is principally andesite, but at many localities the ore is separated from the andesite by a thin layer of the silicated contact phase of the limestone or the sandy basal phase of the limestone. The contact of the ore with the foot-wall andesite as a whole is considerably more regular than that with the hanging-wall limestone. There is less interpenetration of the two masses, yet occasional fragments of andesite protrude into the ore or are entirely surrounded by it, and andesite breccias with ore cement are not uncommon along faults. Andesite dikes or offshoots are rare in the ores and limestone near the contacts, but are known in one locality east of Iron Mountain. The andesite near the contact is altered to

a soft clay retaining andesite texture. The contacts may be vertical or inclined, but are commonly somewhat steeply inclined away from the andesite.

These simple relations of ore to wall rock, are complicated to a considerable extent by faulting, probably to a larger extent than has

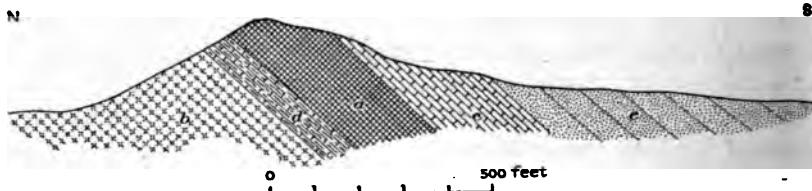


FIG. 4.—Cross section of Desert Mound contact deposit. *a*, Iron ore; *b*, laccolithic andesite; *c*, Homestake limestone; *d*, altered Homestake limestone; *e*, Pinto sandstone.

been proved. Because of the faulting the ore may be nearly or quite surrounded by andesite or by limestone or by any combination of these rocks. The map (Pl. II) indicates the effect of the faulting on the surface distribution. Its effect is probably equally marked on the third dimension.

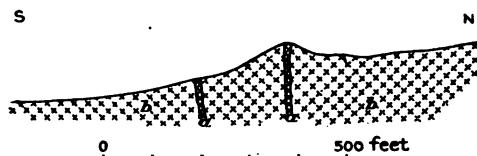


FIG. 5.—Cross section of Great Western fissure veins. *a*, Iron ore; *b*, laccolithic andesite.

The faulting is in considerable part earlier than the ore deposition, as shown by the fact that the fault breccias are cemented by ore. The Desert Mound and the Marshall claim in The Three Peaks area afford good illustrations. Other faults are distinctly later than the deposition of the ore, as on the Chesapeake claim and others on the

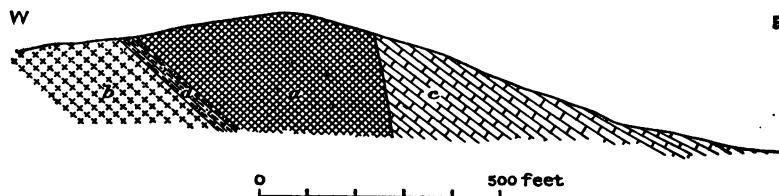


FIG. 6.—Cross section of Lindsay Hill contact deposit. *a*, Iron ore; *b*, laccolithic andesite; *c*, Homestake limestone; *d*, altered Homestake limestone.

slope and on the top of Iron Mountain. The earlier and the later faulting are not certainly to be distinguished in all places in the present state of development of the deposits, for the structural relations developed are in part similar in the two cases. The age of the late



A. SOUTHERN CROSS IRON-ORE DEPOSIT, EAST OF GRANITE MOUNTAINS, LOOKING NORTH.

The ore forms the summit and the dark area on the slope to the right and foreground. The light area to the left is foot-wall andesite. Hanging-wall sediments occupy the lower half of the slope to the right.



B. CHESAPEAKE IRON-ORE FISSURE VEIN, IRON MOUNTAIN. (BOUNDED BY ANDESITE.)



A. GREAT WESTERN IRON-ORE FISSURE VEIN, SOUTHERN PART OF THE THREE PEAKS
LACCOLITH, LOOKING NORTH.



B. IRON-ORE BLOWOUT SOUTH OF IRON MOUNTAIN LACCOLITH, LOOKING SOUTHEAST.

Crystalline magnetite constitutes the hill in the middle foreground. In the distance are the Harmony Mountains.

faulting of the ore deposits is provisionally assigned to the postlava period, because this has been a period of considerable faulting throughout the district.

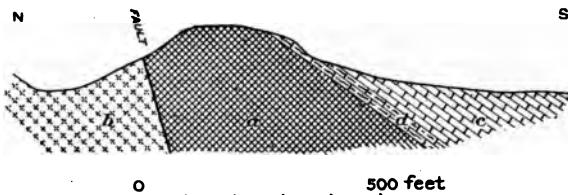


FIG. 7.—Cross section of Blowout contact deposit. *a*, Iron ore; *b*, laccolitic andesite; *c*, Homestake limestone; *d*, altered Homestake limestone.

The shape of the deposits in vertical cross section is incompletely known because exploration has been shallow. Available informa-

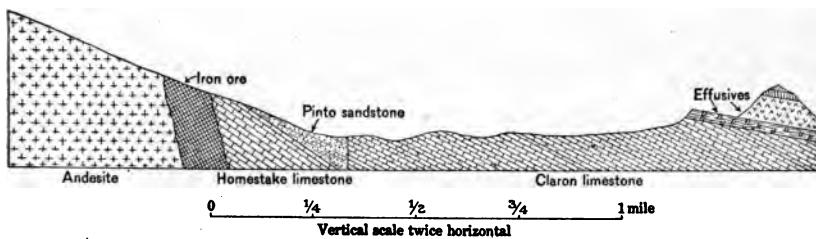


FIG. 8.—Cross section southeastward through Lindsay Hill, showing structural relations of ores.

tion is summarized in figs. 4, 5, 6, 7, 8, and 9. Inferences drawn from the manner of development of the ore are discussed on pages 76 and 85.

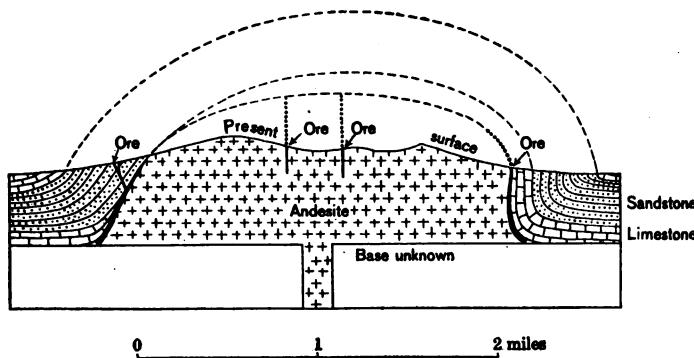


FIG. 9.—Ideal cross section through Iron Mountain laccolith, showing structural relations of ores.

ORE DEPOSITS IN BRECCIAS.

The ore constitutes cements or minute veins in fault breccias formed by the Homestake limestone, Pinto quartzite, or andesite at several localities, as follows: Limestone and quartzite at the Milner mine, Dear, Excelsior, Duluth No. 2, Desert Mound; andesite at the

Marshall, Blowout, Dexter, and Pot Metal claims. At the Desert Mound a fault breccia crosses andesite, ore, and limestone, and magnetite constitutes breccia fragments.

The iron ores lack the associated "iron formation" of ferruginous chert or jasper so characteristic of the Lake Superior iron ranges. The nearest approach to jasper is in ores banded parallel to the walls in the fissure veins in the andesite, and in contact ores with a banding representing original limestone bedding.

The ore deposits nowhere come in contact with the later effusives. However, it is a significant fact, to which attention will be directed in discussion of origin of the ores, that the principal ore deposits are approximately on the level of the general surface upon which the lavas rest, sometimes above it but never below, and that the effusive rocks before erosion must have rested upon the present deposits. (See fig. 9.)

KINDS AND GRADES OF ORE.

The following description applies to the ores as they appear above water level. Pits have not yet been sunk below this depth.

The ore is mainly magnetite and hematite, usually intimately intermixed, but locally segregated. So far as present information goes (and it does not go far below the surface) the magnetite constitutes about 70 per cent and the hematite 30 per cent of the whole. As hematite appears more abundantly below the surface, it is thought likely that deeper exploration will develop a higher percentage of hematite. At the surface the ore is ordinarily hard crystalline magnetite and hematite in porous, gnarled, and contorted masses, with coarsely crystallized quartz and fibrous chalcedony as the principal gangue mineral, filling, wholly or partly, cavities in the ore. Other gangue minerals occurring in small and practically negligible amounts are apatite, mica, siderite, diopside, garnet, pyrite, chlorite, calcite, barite, galena, amphibole, copper carbonates, limonite, and amethyst. Of these minerals barite and galena are more closely associated with the limestone than with the ore. Melanterite, associated with pyrite, was found in process of formation in the long tunnel on the Duncan claim. Beneath the surface the ore is usually softer and contains a larger proportion of soft, bluish, reddish, brownish, grayish, and greenish banded hematite, limonite, and magnetite in greatly varying proportions and relations. The gangue materials are more abundant than near the surface, and calcite is in relatively increased proportion as compared with the quartz. The banding in the contact ore partly represents the bedding of the limestone, which, as will be shown later, the ore replaces. Banding in the dike or vein ores in the andesite is of unknown origin, possibly the result of original deposition. Some of the softer ore at lower levels entirely lacks this banding. Locally, as on the west side of Lindsay Hill, the



A. WAR EAGLE IRON-ORE DEPOSIT, NORTH OF IRON SPRINGS.



B. IRON-ORE CONTACT DEPOSIT AT DESERT MOUND, LOOKING WEST.

Iron ore forms the main hill. To the right is foot-wall andesite; to the left Homestake limestone. The lower slope in the foreground is composed of Homestake limestone and Pinto sandstone.



contact ore contains parallel streaks of a yellow clayey-looking material. On examination this resolves itself into a mixture of iron carbonate, iron sulphate, and glass, and probably some residual clay. Some of the narrow ore veins in the andesite possess a comb structure formed by the meeting and interlocking of apatite crystals projected from the walls (see fig. 10), sometimes not entirely closing the vein.

In the ore breccias the cements are magnetite, limonite, calcite, and quartz. At the Milper mine and elsewhere the magnetite has been deposited first about the fragments, here consisting of quartzite, then hematite, then limonite, but exceptionally in the same locality the reverse order appears.

The texture of the ore as a whole is good for furnace use. The harder ores will need crushing.

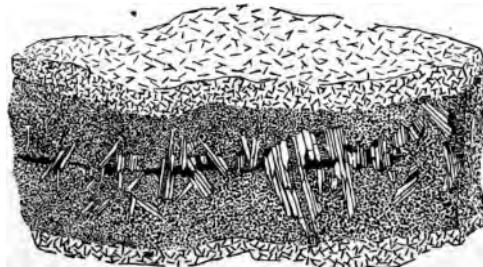


FIG. 10.—Vein of magnetite in andesite. The ore, indicated by the fine dots, does not quite fill the opening. Crystals of apatite penetrate the ore and interlock across the opening. One-half natural size.

For the following information concerning the composition of the ores the writers are indebted to Mr. Fred Lerch, of Biwabik, Minn., and to Mr. R. N. Dickman, of Chicago, Ill., both of whom have exhaustively sampled the ores of the district for commercial purposes. Corroborative figures were obtained from other commercial sources, and in a few cases analyses were made for the writers. In all, about 200 analyses from 400 samples of ores have been available, about two-thirds of them containing determinations only of iron, silica, and phosphorus, and one-third showing the percentages of all the common elements.

The average composition of the ores of the Iron Springs district, determined by combining all available analyses of the ores of the district from surface and pits, is as follows:

Average composition of iron ores of the Iron Springs district.

	Per cent.		Per cent.
Iron.....	56	Copper.....	0.027
Silica.....	7	Sulphur.....	.057
Phosphorus.....	.200	Manganese.....	.196
Lime and magnesia.....	4	Soda.....	1.19
Alumina.....	1	Potassa.....	.80
Water.....	3		

The samples run as low as 45 per cent in iron and as high as 69 per cent. The hard ore in the andesite runs higher on the average than the ore in the limestone. The ore at the surface, with few exceptions, has a higher percentage of iron than that below, the difference ranging from 3 to 12 per cent.

Phosphorus may diminish slightly in the deepest explorations, that is, below about 100 feet, but the distribution is so irregular and capricious that this generalization is doubtful. There are common variations within a short distance, both vertical and horizontal, of 0.050 to 3.18 per cent. A few 10-foot samples of ore run below the Bessemer limit in phosphorus, but practically all the ore as mined will be non-Bessemer ore.

Silica, averaging about 7 per cent, varies between 2 and 28 per cent, the lower figures being more common in the ore in the andesite. There is a distinct loss of silica at the surface, amounting to about 4 per cent as compared with that immediately below the surface.

Lime and magnesia range from 1.5 to 11 per cent. The hard ores in the andesite carry slightly less than the soft ores in the limestone. In both types the deeper ores carry the higher percentage. While both silica and lime are in greater quantity below the surface, corresponding to a lower percentage of iron, the lime and magnesia increase relatively faster than the silica with depth. Whereas at the surface a common ratio of silica to calcium and magnesium oxides is 2 to 1 by weight; below the surface it is more nearly 1 to 1.

Combined water varies from less than 1 per cent in the magnetite to 4 per cent in the soft ores, averaging about 3 per cent. One determination of moisture in crystallized magnetite^a gives 0.45 per cent after heating to 110° C.

Sulphur is present in variable amounts, averaging .057 per cent, but in the deep exploration of one of the deposits, the Duncan, this figure is exceeded and the presence of sulphur becomes a serious consideration. There seems to be no general evidence of increase with depth, so far as exploration has yet gone, but water level has not yet been reached in the explorations.

Copper, titanium, and manganese are present, but not in injurious amounts.

Soda and potassa are determined in a single specimen.^b Their significance is discussed on page 77.

Pl. XX summarizes the available information in regard to the variation of composition with depth.

A comparison of average analyses of Iron Springs iron ores with Lake Superior hematites and with the Clinton hematites of Alabama is made in the following table:

^a Specimen 46113, Lindsay Hill. Analysis by R. D. Hall, University of Wisconsin.

^b Specimen 46333A, Lindsay Hill. Analysis by R. D. Hall, University of Wisconsin.

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[REDACTED]

Comparison of average analyses of Iron Springs iron ores with ores of Lake Superior and Alabama.

	Iron Springs ores.	Lake Su- perior ores. ^a	Alabama hema- tites. ^b
Iron (metallic)	56	59.6	37
Silica.....	7	7.5	13.44
Phosphorus.....	.200	.067	.37
Lime and magnesia.....	4	1.3	16.2
Alumina.....	1	1.5	3.18
Water, above 220°.....	3	4.0	.50
Copper.....	.027		
Sulphur.....	.057	.019	.07
Manganese.....	.196		
Carbonic acid			12.24

^a Average cargo analyses for 1905.

^b Birkinbine, John, The iron ores of Alabama (average analysis by Dr. William B. Phillips): Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 6, 1898, p. 62.

It will be noted that the Iron Springs ores are intermediate in composition between the two other great classes of ores.

SIZE AND QUANTITY OF ORE DEPOSITS.

The iron-ore deposits vary from mere stringers to those having an area of 1,670,000 square feet. The aggregate surface of all the ore deposits of the district is 5,430,000 square feet or 0.2 square miles.

The aggregate tonnage of all grades of ore in the district, determined by multiplying the known area by the best available information as to depth in pits, drill holes, and erosion sections is 40,000,000 tons. The largest single deposit, figured on the same basis, has 15,600,000 tons. It is altogether likely that the figures are much too small rather than too large, because the depths used in the calculation have been those actually observed, and observation has not yet gone to the bottom. Inferences concerning the extension of the ore beneath the present workings, based on the manner of origin of the ore, are discussed on pages 87-89.

DEVELOPMENT.

During the years 1874 to 1876 a small furnace, with a daily capacity of 5 tons, was built and operated at Iron City, 5 miles southwest of Iron Mountain. The product was taken to the then prosperous silver mining camp at Pioche, Nev., and to Salt Lake, Utah. Later the old stack was torn down and a new one, projected to take its place, never rose higher than the foundation. The coal was derived from the Harmony Mountains, 5 miles to the southeast. The ore used in this furnace was taken out of the Duncan claim, one of the southernmost exposures of ore in the Pinto groups of claims, from shallow pits and short tunnels near the surface.

From time to time since the discovery of the deposits, pits and tunnels have been sunk in the ore, principally to meet assessment

requirements, but partly to show up the ore bodies. Some of the more vigorous exploration was conducted during the years 1902 and 1903. The total number of pits sunk to date has been approximately 1,600, of which 30 have gone to a depth greater than 50 feet. The maximum depth has been 130 feet.

Diamond drills have been used only at the Desert Mound, where 5 holes have been sunk. The detailed results of this drilling have been withheld from the United States Geological Survey, though some of the cores have been examined.



A. CONTACT PHASE OF PINTO SANDSTONE WEST OF IRON MOUNTAIN.



B. RETICULATED IRON-ORE VEINS IN ANDESITE.

The dark bands are iron ore protruding on the weathered surface.

CHAPTER VII.

ORIGIN OF THE IRON ORES.

GENERAL.

The principal ore deposits, viz, those near the contact of the andesite and limestone, are partly replacements of limestone. The original bedding of the limestone has been preserved in the ore in a number of places, and there is gradation between the ore and the limestone. These deposits are also in part fillings of fissures in limestone or between limestone and andesite. Where ore occurs within the andesite it fills fissures. The source of the iron-bearing solutions is the same for the limestone replacements and for the vein fillings in the limestone and in the andesite, for their mineralogical and textural characters are the same and in a few cases they are actually connected. Several hypotheses as to this source have suggested themselves: (1) That the ore-bearing solutions were associated with the intrusion of the andesite as "igneous after-effects;" (2) that they were meteoric waters, cold, or heated by contact with the laccolith, acting after the laccolithic intrusions and before the eruption of the surface flows; (3) that they were hot solutions, magmatic or meteoric or both, connected with the late eruptives of the district, deriving the ores from the effusives or from the underlying rocks; (4) that they were cold meteoric waters later than the effusives; (5) that they were due to some combination of these sources. The source of the ore is best explained by the first hypothesis, but later concentrations of the ore have occurred in the order named.

CONCENTRATION AND ALTERATION.

DEPOSITION OF ORE FOLLOWING LACCOLITH INTRUSIONS AS IGNEOUS AFTER-EFFECTS.

INTRODUCTION OF THE ORE.

The general association of the ores with the andesite and their specific association with fissures and faults in the andesite and the immediately adjacent limestones, the nature of the ores and gangue materials, especially the primary association of magnetite with garnet, amphibole, pyroxene, mica, apatite, iron sulphide, and glass,

seem to allow of but one general interpretation, and that is that the ore-bearing solutions were hot, rising from a deep-seated source through fissures in the andesite now filled with ore, at a period closely following the crystallization of at least the outer part of the laccolithic mass.

That the ore was introduced after the hardening and crystallization of the andesite and not before is shown not only by its occurrence in clear-cut fissures in the andesite and by the metamorphism of the andesite near the ore, but also by the lack of anything in the nature of a basic edge in the andesite, by the lack of irregularity in its composition, by the absence of ore for considerable intervals along the andesite contact, and by the fact that the intrusion of the andesite metamorphosed the limestone in a clearly recognizable manner, recrystallizing it, decarbonating it, rendering it more siliceous, and indurated the Pinto sandstone to a quartzite spotted by the segregation of ferrous iron in the form of amphibole—all before iron was introduced.

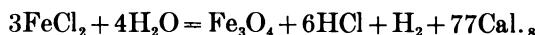
The ore-bearing fissures within the andesite (see p. 67) are of a kind which results from cooling and stretching. They are curved, tapered, branching, and in parallel sets, some of them minutely parallel and anastomosing (see Pl. XXI, *B*). The contraction accompanying the crystallization of the lava may also account for the ore-bearing fissures and faults following the periphery of the andesite, and affords a good explanation for the occurrence of ores at the contact in lens-shaped masses with their longer diameters parallel to the contact. The crystallization of a laccolith the size of the Iron Mountain laccolith from a viscous or glassy condition would yield a radial shortening of 200 to 500 feet, depending on the depth assigned to the laccolith. The parting of the andesite from the limestone during cooling finds its analogue in the parting of a casting from the mold.

The association of the ores with heavy anhydrous silicates, characteristic of slow-cooling intrusions, eliminates the possibility of development from the later effusives, which develop at their contacts minerals of a different kind and association, listed on page 85.

It is thought likely that the ore, at least the part within the zone of observation, was originally deposited as magnetite rather than as sulphide. Had it originally been sulphide, the subsequent alteration to magnetite would scarcely have left unchanged the closely associated silicates. The magnetites are nowhere observed to pass down into sulphides, although the ground-water level has not been reached. Until it has been reached, statements regarding the sulphides must be regarded as tentative.

Assuming, then, in the absence of negative evidence, that the iron was deposited primarily as magnetite, the iron may be supposed

to have been carried as a ferrous compound of some kind, possibly chloride or carbonate or sulphate, and its deposition as magnetite required partial oxidation. At the time of the intrusion the covering of the laccolith was probably about 4,000 feet thick, which would give little opportunity for the entrance of oxygen from the air. The expulsion of the carbon dioxide from the limestone which preceded the deposition of the ore may also have aided in keeping out oxygen. The probable alternative source of the oxygen is that derived by the breaking up of the water. Ferrous chloride reacts with water at temperatures above 500° C., with the simultaneous development of magnetite, hydrochloric acid, and free hydrogen, as follows:^a



As magnetite is soluble in hydrochloric acid, there could obviously be no precipitation as long as this acid remained, but it is neutralized by the limestones which the solutions meet and the ore precipitated. Magnetite has abundantly replaced limestone in this district, as shown by the retention of the bedding structure of the limestone. Interchange of the ferrous iron with the lime would also precipitate the iron as iron carbonate, which is found associated with the magnetite. Had the iron been carried in ferric solution, limestone would have precipitated it as hematite. Possibly the hematite found in small amount in the ore may be so explained. Magnetite would also be precipitated by the evaporation and dispersion of the solution, which would result from the lowering temperature and pressure as the solutions left the andesite. Hydrochloric acid is easily volatilized with water, making it difficult to dehydrate a chloride without losing chlorine. So far as hydrochloric acid was lost, magnetite would be deposited. Kahlenberg^b regards this process as entirely adequate to accomplish abundant precipitation of magnetite under the stated conditions. The existence of magnetite in dikes in the andesite or as cement in quartzite breccias, where limestone, as an alternative precipitating agent, is not present, is perhaps to be explained by this method of precipitation.

One of the conspicuous features of the contact metamorphism of the limestone and the metamorphism of the andesite adjacent to the ores is the introduction of soda. The ore of the first concentration itself shows a dominance of soda over potassa. These facts suggest that soda has been introduced not only into the limestone during its metamorphism but also later with the iron. It would be easy to explain the transportation of this salt in the chloride

^a Moissan, Henri: *Traité de chimie minérale*, vol. 4, 1905, p. 330.

^b Personal communication, Louis Kahlenberg, Univ. Wisconsin, 1907.

solution above hypothesized for the carrying of the iron. Lindgren finds salt in inclusions in vein quartz with a probable igneous origin. This most volatile of all the common mineral compounds is an abundant emanation product of volcanoes. It may be noted that sodium chloride would be decomposed by reaction with silicic acid undoubtedly met in the limestone contact, precipitating the sodium in its present silicate combination.

The introduction of apatite, garnet, amphibole, and pyroxene, all of them containing lime, and the greater abundance of these minerals nearer the limestone than elsewhere, suggests reaction between the hot solution and the limestone. It is not certain, however, that the limestone was necessary as a precipitating agent for the reason that these minerals are also found in fissures in the andesite entirely away from the limestone. The deposition of silicates may equally well have been a function of the change of temperature of the solutions. The order of deposition of the principal minerals of this first concentration seems to have been: (1) Magnetite (and other oxides), pyrites, and amphibole, apatite, and garnet; (2) diopside.

Interlayered with the magnetite and closely associated with glass is amorphous iron carbonate, the genetic relations of which to the other minerals are not known.

SOURCE AND CONDITIONS OF THE ORE-BEARING SOLUTIONS.

Judging from records available elsewhere as to flow of meteoric waters with depth, the 4,000 feet of rock covering the laccolith probably prevented ready access of abundant meteoric waters. Such as were present in the rocks may have reached high temperatures adjacent to the laccolith, and may have aided in the ore-depositing processes. But that the principal source of the solutions was the hot andesite magma seems to be implied by the nature of the minerals deposited and their association, and manner of association, with the laccolith. These solutions were ejected after at least the outer parts of the laccolith had crystallized.

That the temperature of the solutions was high is clearly shown by the nature of the materials deposited. The temperature was above the critical temperature of water—365°—judging from experimentally determined temperatures necessary for the crystallization of certain silicates similar to those here found.^a A temperature higher than the critical temperature is further indicated by the presence of glass in the ores locally. From the fact that the fusion of the contact phase of limestone probably took place at temperatures ranging upward from 1,000° (see p. 36), and that the ore is in veins in this

^a Allen, E. T., Wright, F. E., and Clement, J. K., Minerals of the composition $MgSiO_3$; a case of tetramorphism: Am. Jour. Sci., 4th ser., vol. 22, 1906, p. 399.

phase and does not replace it, it may be inferred that the ore-bearing solutions were introduced into the limestone after its temperature had fallen below 1,000°. There is nothing to show that the temperature of the wall rock may not have been much lower, but the introduction of the ore followed so closely that the presumption is that the temperature may not have been much below 1,000° C. The rock pressure above the laccolith, amounting at a maximum to the weight of 4,500 feet of rock, was sufficient to hold the solution in a liquid state at temperatures of less than 365°. The hydrostatic pressure, which was probably the only effective one, was sufficient to hold the solution in a liquid state below temperatures of 325° C.

It is concluded that the solutions were probably after-effects of the andesite laccolith intrusions.

It is perhaps better to refer the solutions vaguely to "after-action" than to attempt more specifically to indicate whether they have come from the andesite itself or from some deep reservoir common to the andesite and the solutions. The abundant presence of magnetite in the andesite—3½ to 4 per cent—as so-called "reaction rims" about biotite, and to a less extent about hornblende, suggests a possible connection between the andesite and the ore-bearing solutions. The occurrence of magnetite in these relations has been held by Washington^a to indicate the instability of the biotite and hornblende under surface conditions and their breaking down into paramorphic magnetite and augite, the latter being less abundant about the biotite than about the hornblende, and thus unimportant or altogether lacking in the Iron Springs rocks. By others the magnetite rims have been explained as due to absorption (solution) by the surrounding magma. The abundance of hydrogen gas (see p. 81) suggests that the development of the magnetite has resulted from the breaking down of water. But whatever the origin of the rims, it is apparent that the separation of the magnetite has occurred late in the cooling of the andesite. It would simplify matters greatly if this segregation of magnetite could be shown to be definitely related in some way to the ore-bearing solutions coming out of the andesite, but the writers know of no way to do this.

CONCENTRATION OF ORE BY WEATHERING PRIOR TO ERUPTION OF TERTIARY LAVAS.

When erosion had uncovered the ore deposits, it is reasonable to infer that the same processes of concentration that may be observed to-day were effective. These are described on pages 82-84.

^a Washington, H. S., The magmatic alteration of hornblende and biotite: Jour. Geol., vol. 4, 1866, pp. 257-282.

CONCENTRATION UNDER THE INFLUENCE OF TERTIARY LAVAS.

Inference of the modification of the ores by contact of the late lavas is to be drawn from the topographic relations of the ores and lavas. The lavas at one time rested directly against the andesitic cores of the mountains, upon the eroded edges of limestones and other sediments, and upon the ores. The principal ore deposits on the lower slopes of the hills are exposed at about the same elevation as the lower part of the lavas. Erosion has cut the lavas back, so that they now fringe the ore-bearing areas. (See Pl. II.) The heated waters associated with the lavas flowed along the andesite slopes where the ores occur.

Under the influence of the lavas and accompanying solutions, limonite was dehydrated, limonite and hematite were deoxidized (a process easily brought about in the laboratory by passing steam over such ores) and all of the minerals were coarsely recrystallized, making the upper parts of the deposits nearest the lavas consist principally of coarsely crystallized magnetite and some hematite. Hot solutions from the lavas introduced new minerals into cavities in the ore then and previously formed. These minerals consist principally of quartz and chalcedony and to a subordinate extent of hematite, magnetite, siderite, limonite, chlorite, calcite, barite, galena, and the copper carbonates. The heavy anhydrous minerals of the early deep-seated concentration were not developed.

Immediately beneath the lavas at observed contacts with the Claron limestone, there has been introduced, obviously from the lavas, an abundance of more or less iron-stained chalcedony, with a jasy appearance, identical with that observed in the upper parts of the ore deposits. The lavas themselves contain abundant chalcedonic quartz, filling large and small cavities and also minutely disseminated through the rock so intimately as to suggest hot solutions accompanying and immediately following the cooling of the lavas.

To test the conclusion that the chalcedony, taken to be the chief contribution of the extrusions, was not really deposited from meteoric waters, determination was made of the gas content of the chalcedony associated with the ore, for which the writers are indebted to Rollin T. Chamberlin of the University of Chicago. This analysis is compared in the following table with analyses of gas content of the andesite of the Iron Springs district by Mr. Chamberlin, one of volcanic emanations by Fouqué, and one of crystalline rocks by Tilden.

Analyses of gas content of chalcedony associated with ore, of andesite, of volcanic emanations, and of the average of five crystalline rocks.

	A.	B.	C.	D.
H ₂ S.....	0.00	0.12	.....
CO ₂	13.93	13.93	0.22	34.104
CO.....	11.26	18.18		
O ₂.....	.00	.00	21.11	8.422
CH ₄	4.00	3.63	.07	3.224
H ₂	64.40	58.71	56.70	52.134
N ₂	6.44	5.43	21.90	2.072
Volume of gas per volume of rock.....	100.03	100.00	100.00	99.958
	.82	.82	.....	4.5

A. Specimen 46613. Chalcedony in ore. From Crystal claim, Iron Mountain, Iron County, Utah. Analysis by Rollin T. Chamberlin. 0° C. and 760 mm. pressure.

B. Specimen 46612. Andesite from Granite Mountain, Iron County, Utah. Analysis by Rollin T. Chamberlin. Same conditions.

C. Gaseous emanations from Santorin. Analysis by Fouqué. (Santorin et ses éruptions, p. 225.) When studied spectroscopically these gases were found to have traces of chlorine, soda, and copper.

D. Average of five crystalline rocks. Analysis by Tilden. (Chem. News, November 9, 1897.) Standard conditions.

The gases in the chalcedony associated with the ore are roughly similar in their proportions to those of igneous rocks and volcanic conditions and differ generally in their proportions from the gases of the atmosphere. The gas analyses therefore furnish corroborative evidence of the introduction of the chalcedony directly from the late lavas.

That iron was introduced into the underlying rocks by the hot lava solutions is shown by its intimate relations with the chalcedony in the jaspery phases at observed contacts of the lava and by its occurrence in crystalline masses with chalcedony, partly or wholly filling cavities in the ore. The lava masses themselves are locally rich in iron. In the Antelope Springs area samples of the lavas (not veins) run as high as 6.5 per cent metallic iron. A few veins of magnetite and hematite are found in the lavas, which may have come from late lava solutions or from meteoric waters acting subsequently. The microscope discloses reaction rims about the biotite (as in the andesite, p. 48) formed during and following the flow of the lavas. The segregation of iron salts in the magma is further demonstrated by schlieren in the groundmass of the lavas, some of them light colored and some of them darker colored owing to a higher content of iron, and still further by the occasional segregation of magnetite or siderite about amygdaloidal cavities, both as fillings and as segregations in the adjacent groundmass. It is easy to conceive that iron salts got into the aqueous solutions which were in the lava at this stage of the cooling.

The introduction of calcite, quartz, siderite, limonite, galena, barite, and copper carbonates from the lavas is well shown at Chloride Canyon, where immediately below the contact these minerals appear in veins or disseminated through the rock. Chlorite is not found

here, but is present elsewhere in the same associations and was probably also introduced by the lava waters.

So obvious and striking are the effects of the extrusion of the lavas upon the principal ore deposits of the lower slopes of the laccoliths that the question was raised in the field study whether this concentration could not have been the principal and perhaps the only one, but the evidence seems to be conclusive that the concentration under the influence of the Tertiary lavas was after all relatively slight. Limestones in contact with the lava, but away from the andesite, do not carry iron-ore deposits, although reddened and silicified by solutions from the overlying lava. The minerals (barite, galena, copper carbonates, etc.) deposited in the ore by these solutions are distinctly later than the main mass of the ore, which is intimately associated with heavy anhydrous silicates characteristic of deep-seated intrusions. The coarse recrystallization of the ore under the lava influence seems to be shallow and the recrystallized ore to be superposed upon ore of finer and softer texture.

It seems a reasonably safe conclusion that during and following the lava extrusions both hot meteoric waters and waters contributed by the lavas flowed down the andesite slopes, that they were intermingled, and that the results of their work are not to be closely discriminated. The contribution of minerals from the lavas, however, would seem to require emphasis on the effectiveness of the waters from them.

ALTERATIONS SUBSEQUENT TO TERTIARY ERUPTIONS.

Observation has not yet gone below water level, so that a comparison of the ores of the weathered and unweathered zones can not be made. In general the characteristics of the ore are determined by conditions other than weathering. However, the ores as a whole are more porous near the erosion surface than below in pits. There is less calcite above than there is below. It is inferred that there has been leaching of the calcite above and perhaps redeposition below. The calcite is partly in fine granular form, incrusting ore and rock surfaces, and is similar in appearance to carbonate seen about some of the old vents of hot springs in this district. The possibility is therefore suggested that the solution and redistribution of the calcium carbonate went on partly through the agency of warm waters during the period of the cooling of the lava. However, redistribution is yet going on, through the agency of cold meteoric water, with sufficient rapidity to incrust rapidly changing erosion surfaces.

The magnetite commonly alters to limonite and hematite, in thin incrusting films, not directly at the surface, but in the solution cavities and in fissures near the surface. This alteration seems to

be at a maximum near the contact of ores and the adjacent rocks at the surface. Iron sulphide is changed to limonite and melanterite, some of which is removed in solution. Iron carbonate alters to limonite.

Apatite has been altered to osteolite and leached in the upper parts of the ores to a very considerable extent. Frequently the entire crystal of apatite has disappeared, its former presence being indicated only by the shape of the cavity. Presumably this apatite is redeposited below. This does not necessarily mean that the ores beneath the surface will run higher in phosphorus than at the surface, for the reason that there may be concentrated at the present surface a large part of the phosphorus which has come from the erosion of the overlying materials—a relatively larger amount of phosphorus than has been leached from the present surface and carried farther down.

Erosion has cut down the ore deposits many feet, as shown by abundant ore débris on the slopes. The ore is fissured. Extreme temperature changes spall off considerable blocks bounded at the sides by fissure planes. The ultimate product is magnetic sand, abundantly found on the lower slopes. For most of the district this erosion has gone on much less rapidly in the ore than in the adjacent andesite and limestone, with the result that the ore stands up in conspicuous black masses above the surrounding rocks. In a number of places, however, as on the Vermilion, Lindsay, Enterprise, part of the Mount Lion group, Comstock, Sunbeam, Wellington, Queen of the West, Black Hawk, Pinto mine, Pinto Nos. 3, 5, and 6, Burke No. 5, Red Clouds, and Duncan No. 1 claims, the ore has been cut down flush with the surrounding rocks. In these places the ore is uniformly softer than where standing up in conspicuous crags. It may be that the hard crystalline surface ores, serving more or less as protecting caps, have been locally undermined and cut off, leaving the underlying softer ore unprotected, with the result that it is cut down fully as rapidly as the adjacent rocks.

There is no evidence that weathering contributed to the deposits any considerable amount of ore from adjacent rocks. During erosion the magnetic iron of the andesite is concentrated into magnetic sands, as is the magnetite derived from the disintegration of the ore deposits. If alumina be assumed to remain constant during weathering it will be apparent from the analyses of the andesite that a small percentage of iron has been lost. With this percentage of loss it would require the weathering of a mass 100 feet thick and 0.2 square mile in area to yield a million tons of 56 per cent ore.

Iron is only slightly leached from the limestone during weathering, all but a minute part remaining in the residual clay. The residual soil from the Homestake limestone has been removed and the ore

deposits lack clay characteristic of residual deposits. If the slight amount carried off during weathering be assumed to be available for the development of ore deposits, there seems to be no reason why limestone of this low percentage of iron should yield sufficient ore for ore deposits in the particular localities where they now occur and not in others where the limestone contains as much iron.

SUMMARY OF MINERAL ASSOCIATIONS OF ORES IN RELATION TO ORIGIN.

The first effect of the andesite laccolith intrusions was the development of the silicated contact phase of limestone containing the minerals of column 1 in the following table. Slightly later, veins containing much the same association of minerals cut andesite and limestone (column 3). About the same time came the introduction of ore-bearing solutions in veins both in andesite and limestone and also replacing limestone (column 2). The minerals deposited are much the same as those previously developed in the contact limestone, though albite and orthoclase, present in the contact phase, have not been found in the ore, while apatite and garnet are more abundant in association with the ores than elsewhere in the contact phase. So similar are the groups of minerals developed up to this point and so close their association that they can not be sharply separated. There can be little doubt that they are developed under no greatly varying conditions with insignificant time intervals. According to Lindgren's classification,^a the minerals of these groups are characteristic both of products of aqueo-igneous solutions, like pegmatites, and of products of aqueous solutions, in the lower contact zone. Criteria do not seem to be available in the Iron Springs district for clearly separating the two classes. The evidence appears to indicate that they all result from the andesite intrusion, principally through the transfer of pneumatolytic vapors, but that in the limestone contact they are also developed by simple elimination of lime and magnesia, and the recrystallization of the residue.

Later, solutions from the lavas introduced another and clearly distinguishable group of minerals, listed in column 5. These are found principally near the contact of the lavas with the pre lava erosion surface, and were developed, therefore, under essentially surface conditions. They correspond closely to the minerals listed by Lindgren^a as characteristic of these conditions.

^a Lindgren, Waldemar, The relation of ore deposition to physical conditions, *Econ. Geol.*, vol. 2, 1907, pp. 122-125.

Mineral associations of ores.

1.	2.	3.	4.	5.	6.	7.
Minerals developed in limestone at contact of andesite intrusive.	Minerals of first ore concentration under influence of andesite intrusive.	Minerals in veins in contact limestone and andesite. ^a	Minerals of late ore concentration under influence of effusives.	Minerals of same age and origin as 4 but occurring in late veins in limestones.	Minerals in veins and amygdalules in lavas.	Weathering minerals.
Quartz.....	Quartz.....	Quartz.....	Quartz, chalcedony, etc.	Quartz, chalcedony, etc.	Quartz, chalcedony, opal, etc.	
Calcite.....	Calcite.....	Calcite.....	Calcite.....	Calcite.....	Calcite.....	
Diopside.....	Diopside.....	Diopside.....				
Andradite.....	Andradite.....	Andradite.....				
Andradite (?).....						Osteolite.
Apatite (?).....	Apatite.....	Apatite.....				
Actinolite.....	Actinolite.....	Actinolite.....				
Magnetite.....	Magnetite.....	Magnetite.....				
Hematite.....	Hematite.....	Hematite.....				
Limonite.....		Limonite.....		Limonite.....		
Albite.....						
Orthoclase.....						
Wollastonite (?).....						
Phlogopite.....	Biotite.....	Phlogopite.....				
Serpentine.....	Kaolin.....					
Kaolin.....						
Andalusite.....		Epidote.....				
			Chlorite. ^b			
			Copper carbonates.			
			Siderite.			
				Pyrite.		
				Copper carbonates.		
				Siderite.		
				Barite.		
				Galena.		
				Chalcopyrite.		

^a Slightly later than those of column 1 and of about the same age as ores, but containing no ore.^b Found in one locality to depth of 80 feet in porous ore, but probably still due to action of effusives.**CONCLUSIONS AS TO THE ORIGIN OF THE ORES.**

If the foregoing reasoning is correct, the events leading up to the completion of the ore deposits in their present form are in outline as follows:

(1) Intrusion of andesite laccoliths in Paleozoic and Mesozoic sediments, with consequent tilting of the strata in quaquaiversal manner about the laccolith and contact metamorphism of the zone adjacent to it, accompanied and followed by fissuring, jointing, and faulting.

(2) Entrance of hot ore-bearing solutions through fissures in the andesite into the adjacent sediments, depositing ore as dikelike masses in fissures in the andesite, as fissure fillings and replacements in the limestone, and as cements in breccias of andesite, limestone, and quartzite. The solutions introduced also garnet, diopside, amphibole, phlogopite, apatite, calcite, quartz, and pyrite. Most of these minerals had also been developed in the limestone by the preceding contact metamorphism. Soda was conspicuously increased in the wall rocks. It is thought that the solutions were pneumatolytic after-effects of the andesite intrusion.

(3) Erosion, developing mountains with andesite cores, encircled by belts of sediments at uniform elevations on the slopes, except where displaced by faults, or where cut back by differential erosion. The areas between the mountains were left with low relief. The ores were exposed and partly eroded, calcite, apatite and perhaps other gangue materials were leached and redeposited below. There was more or less oxidation and hydration of the ores along fissures beneath the surface.

(4) Extrusion of the Tertiary lavas over the entire area, furnishing hot magmatic waters and heat to meteoric waters, and thereby developing coarsely crystalline magnetite and hematite in the ore deposits and especially at the surface, leaching the gangue materials so far as they were left by weathering near the surface, and depositing in the cavities chalcedony and to a slight extent magnetite, hematite, limonite, siderite, chlorite, barite, calcite, galena, and the copper carbonates.

(5) Erosion, reexhuming the andesite mountains from under the lavas and bringing to light the sediments and ores on the slopes; this was accompanied by local surface oxidation and hydration of the ores and leaching of the gangue materials, chiefly calcite, but also apatite. Differential erosion caused the ore in some cases to stand above the adjacent rocks, and in others, where the hard cap was cut off, brought the softer underlying ores well down to the level of adjacent rocks.

(6) Preceding and accompanying (5) occurred faulting of the ore deposits, developing structural relations not in all cases to be distinguished from those determined by faulting before deposition of the ores.

BEARING OF THE THEORY OF ORIGIN UPON FURTHER EXPLORATION.

Exploration has not yet demonstrated the depth of the ore deposits. The greatest known depth is at the Pinto group of pits, south of Iron Mountain, where 130 feet is known from the pits and topography. At the Desert Mound drilling may have gone deeper, but the records are not available to the writers.

If the theory of the writers as to the origin of the ore is correct, there are certain fairly well-based inferences to be drawn as to depth and shape of the ore deposits.

If the ore-bearing fissures in the andesite are true stretch fissures determined by the crystallization of the lavas, it may be inferred that they will show the same features with depth as at the surface; that is, curving, pinching out, branching and occurrence in parallel sets. There seems to be no reason why these vein deposits should not go to a very considerable depth, this being determined by the depth to which fissuring had occurred at the time of the extrusion of the ore-bearing solutions.

The ores at and near the andesite contact are determined in their shape and distribution partly by replacement of limestone, partly by peripheral tension fissures and other joints and faults, partly by faults later than the ore deposition, and finally by erosion. A calculation of the radial shrinkage of the andesite mass in cooling makes it between 200 and 500 feet, depending on the thickness assigned to it. A part of this shrinkage is probably accounted for in the stretch fissures and faults in the andesite. A part of it has with equal probability furnished space for ore deposition at the periphery. At the sides of the andesite these spaces would remain open during and following their development, whereas on the slopes and on top gravity would tend to close them as fast as developed. The deposits therefore should have their maximum width where the contacts are vertical or nearly so and should thin out where the slopes become flatter. The conception of the authors as to the relations of the fissures to the andesite before erosion took place is illustrated in fig. 8. This figure does not take account of modifications of shape of the ore bodies due to replacement of the limestone or due to fissures normal to the andesite periphery, which are believed to be subordinate. Erosion has now cut down sufficiently far on the eastern and southeastern sides of the several laccoliths to expose vertical or nearly vertical contacts. On the southwestern side of the Granite Mountain and Iron Mountain laccoliths the erosion plane has exposed a very gently dipping contact plane between andesite and limestone. The wide extent of the deposits at these places, especially at the southwestern side of Iron Mountain, is largely due to the fact that the erosion plane is so nearly parallel to the plane of contact. It does not indicate that the deposits are necessarily wider when measured in a direction normal to the contact than they are elsewhere in the district; indeed, if fig. 9 represents approximately the shape of the openings which determined the ore deposition, the deposits here may well have been thinner than elsewhere. Under these conditions vertical faulting has greater effect on the surface distribution.

It follows from the above considerations that the maximum depth of the ore deposits near the contacts may not be greater than the depth to which the andesite-limestone contact extends, and this is determined by the thickness of the andesite laccolith and whether it breaks across the limestone layers or has tilted them up in such a manner that the contact is approximately parallel to the bedding. In view of the fact that the limestone is tilted steeply where erosion has exposed the sides of the laccolith, it may be assumed that the limestone may be in contact with the andesite as far down as the laccolith goes. Therefore the thickness of the laccolith becomes the determining factor. Erosion has allowed no direct means of measuring this thickness in this district, for the bottom is nowhere exposed. A comparison of the hor-

izontal dimensions of these laccoliths with those described by Gilbert at the Henry Mountains, where the vertical depth also is known, leads to the conclusion that the depth of the "bell" of the Iron Mountain laccolith (the one with outlines best determined) may not exceed 2,500 feet. The other laccoliths are so covered with desert deposits that their horizontal dimensions are not known, and hence even this means of determining their depth is not available. Such comparison affords a very uncertain means of determining the depth of laccoliths in view of the fact that their shape and size depend so much on the nature and structure of the rocks intruded, as well as on the relative densities of the intrusive and intruded rocks. (See pp. 47-48.)

For the deposits resting on gently-dipping slopes, such as those southwest of Iron Mountain, the maximum depth is likely to be found in the direction of dip. Vertically they rest directly upon andesite or upon the contact phase of the limestone, except where they are above ore-filled fissures in the andesite, in which case the deposit is likely to narrow considerably in a vertical direction when it reaches the fissures.

It will be noted that on the western side of Iron Mountain the Cretaceous quartzite comes directly into contact with the andesite at an elevation considerably higher than the limestone-andesite contact on the southern and eastern sides of the laccolith where the ore is exposed. Ores are found cementing brecciated quartzite, but do not constitute important deposits. The lack of important ore deposits along this contact may be explained by the fact that replacement is not possible in the quartzite and that any fissure veins developed at the contact through the contraction of the andesite would be immediately closed by gravity, for the quartzite rests against the andesite with a dip of 35°. There is nothing in the supposed origin of the ores to preclude the possibility that ore deposits may be found beneath the quartzite along the limestone-andesite contacts, especially farther down on the steeper slopes of the andesite. If deposits are there, it may be pointed out that their size has not been diminished by erosion.

The uniform association of ore with andesite laccoliths in this locality, as well as in the district extending southwest to the Bull Valley and beyond, outlines the first rule of exploration—that the andesite laccoliths be found and their boundaries determined. The effect of the laccoliths upon topography is so marked that this may be done at a distance of many miles. (See p. 16.) From high points in the Iron Springs district it is easy to determine the southwestward extension of the laccolithic area, and therefore of the possible ore-bearing area.

The laccolith determined, its contact with the adjacent sediments should be carefully followed.

The location of iron-ore deposits usually makes itself evident on the weathered surface, but not infrequently the mass of débris which

has shifted down the slopes makes it impossible to determine the true outline of the deposit without sinking pits. Where iron-ore fragments are found in the wash at the surface it may be assumed that they came from farther up the slope. Following the wash up the slope, a point will be reached where no iron fragments are to be seen, usually indicating that the upper edge of the deposit has been passed; but it has been found in a few localities that the overwash from the upper slopes has been so thick and heavy that it completely obscures the upper side of the ore deposits, and the first iron-ore fragments appear some feet or yards farther down the slope. The presence of a few fragments, or even of a single fragment, of iron ore in the wash is often sufficient to indicate the existence of an ore deposit several hundred yards away, which may be found by following up the wash and carefully watching its change in iron content.

Where the laccolith and sedimentary rocks are found in direct contact it does not necessarily follow that ore will not be found deeper down along the contact. Replacements are usually irregular, and the source of the solutions is not from above. So far as the ores are fillings of fissures developed around the periphery of the andesite by its crystallization, it is easily conceivable that these openings would be irregular, both horizontally and vertically, and that where the dip of the laccolith contact is low, gravity might close them altogether, so that the appearance or nonappearance of ore on the erosion surface would be determined merely by the extent to which the erosion surface had cut down.

In underground exploration the fact should not be lost sight of that the deposit may show the same range of irregularity with depth that it does on the erosion surface; in other words, that all the factors known to have determined the peculiarities and shapes of deposits on the erosion surface, which are discussed in this paper, should be taken account of in the underground exploration.

CHAPTER VIII.

COMPARISON OF IRON SPRINGS IRON ORES WITH OTHER IRON ORES.

BULL VALLEY DISTRICT.

The Bull Valley district lies about 25 miles to the southwest of the Iron Springs district, extending from Garden Springs on the northeast southwestward to Bull Mountain and 40 or 50 miles beyond. (See fig. 11.) The district, which has only recently been explored

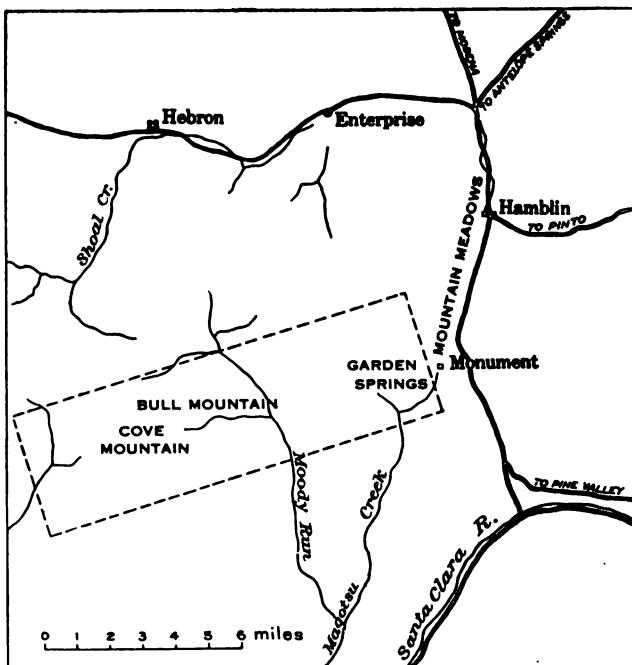


FIG. 11.—Sketch map of Bull Valley district, Utah.

and staked, is much more difficult of access than the Iron Springs district and is consequently less well known. It may be reached from the Iron Springs district by team by way of Pinto, Hamblin, and Enterprise, or on horseback by way of Pinto, Hamblin, Mountain

Meadows Valley, Magotsu Creek, and Moody Run. The nearest railway station is Modena, 28 miles distant by way of Enterprise. The area is covered by the St. George topographic sheet of the Powell Survey (1891), but the map is so imperfect and generalized that it is of little use.

The principal ore deposits lie several miles below the headwaters of Moody Run, which empties into Magotsu Creek 10 miles below the Mountain Meadows. From this point they extend eastward about 3 miles to Garden Springs, located a short distance west of the Mountain Meadows monument, the site of the famous Mountain Meadows massacre. To the southwest, deposits occur on Bull Mountain 2 or 3 miles distant and on Cove Mountain an equal distance beyond.

The essential geological features of the district are the same as those in the Iron Springs district—a series of laccoliths with sediments dipping quaquaversally away from them, surrounded and overlain by flat-lying lavas, the whole being bounded on north and west by later flows of basalt. The contour of the district is rougher than that of the Iron Springs district and the evidences of volcanism are more conspicuous on account of the presence of basalt flows and cinder cones. The general aspect is barren and forbidding. The same topographic and geologic conditions are said to extend for about 40 miles to the southwest into Nevada, and ores are reported from this area.

The ore deposits were examined in their discontinuous occurrence between the headwaters of Moody Run on the west and Garden Springs on the east, and were found to be similar in almost every feature to those of the Iron Springs district. The principal deposits lie within the andesite associated with limestone fault blocks, and subordinate ones follow the main contact of andesite and limestone, which crosses Moody Run in a northeast-southwest direction, dipping to the southeast. Flat-lying flows fringe the ore-bearing areas. On the south are acidic flows and tuffs, on the north acidic flows and tuffs and basalts. A white band near the base of the acidic lavas is very conspicuous and for most of the district is sufficiently near the limestone-andesite contacts to make it useful to explorers as a guide in locating the ores.

The greatest width of ore observed at the surface was 115 feet. However, it was not sufficiently well exposed to make it certain that this 115 feet was continuous ore. This particular deposit has a length of approximately 700 feet.

The iron is both magnetite and hematite, as in the Iron Springs district, but the hematite on the lower slopes takes on a fine granular texture and a steel-blue color which is not seen in the Iron Springs district.

The composition of the ore at the surface, as sampled by Le Brothers, is as follows:

Composition of the Bull Valley district ores.

[Analyst, Fred Lorch, Biwabik, Minn.]

	Iron.
Across 150 feet, Pilot No. 9.....	58.98
Across 250 feet, Pilot No. 8.....	52.28
Across 60 feet, Pilot No. 7.....	52.08
Pilot No. 12.....	56.46
Across 40 feet, Pilot No. 7.....	64.13

There has been a small amount of pitting, trenching, and tunneling, but these amount only to scratches in the upper parts of the deposit.

DEPOSITS OF SIMILAR ORIGIN IN OTHER DISTRICTS

Ores similar to those of the Iron Springs district, consisting principally of magnetite in veins (not magmatic segregations in situ) in igneous rocks or near the contact of igneous rocks and limestone, in both combinations, are known at many localities in western North America, as follows:

In Mexico, where nearly all the iron ores are of this character, their distribution and occurrence being summarized by Hill^a and Aguilera.^b The Durango deposit is described in a number of papers.

In several localities in San Bernardino County, Cal.,^c and in the Redding quadrangle of northern California.^d

In Lyon County, Nev., and in several other localities in the Great Basin.^e

In Stevens County, northeastern Washington,^f Texada and Vancouver islands, British Columbia,^g and Kamloops, British Columbia.

At Fierro^h and Chupadera Mesa, New Mexico.ⁱ

In the Taylor Peak, White Pine, and Cebolla districts in Piñon and Gunnison counties, Colo.^j

At Iron Mountain, Missouri.^k

This list of localities is far from complete and no attempt is made to cite all the publications concerning the districts named. It is

^a Hill, R. T., The occurrence of hematite and martite iron ores in Mexico: Am. Jour. Sci., Vol. 45, 1893, p. 112.

^b Aguilera, José G., The geographical and geological distribution of the mineral deposits of Mexico: Trans. Am. Inst. Min. Eng., vol. 32, 1902, pp. 503-505.

^c Leith, C. K., Iron ores of the western United States and British Columbia: Bull. U. S. Geol. Surv. No. 285, 1906, pp. 194-200.

^d Diller J. S., Iron ores of the Redding quadrangle, California: Bull. U. S. Geol. Survey No. 1903, pp. 219-220.

^e Manuscript notes furnished authors.

^f Leith, C. K., op. cit., pp. 195-196. Report on the iron ores of the coast of British Columbia: the Provincial Mineralogist: Dept. of Mines, Victoria, B. C., 1903, 30 pp.

^g Manuscript furnished the authors by R. W. Hills.

^h Keyes, Charles R., Iron deposits of the Chupadera Mesa: Eng. and Min. Jour., vol. 78, 1904, p. 60.

ⁱ Manuscript notes, summers of 1905 and 1906, Van Hise, Leith, Harder, and Ward.

^j Nason, Frank L., A report on the iron ores of Missouri: Missouri Geol. Survey, vol. 2, 1892, pp. 1-10.

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The composition of the ore at the surface, as sampled by Lerch Brothers, is as follows:

Composition of the Bull Valley district ores.

[Analyst, Fred Lerch, Biwabik, Minn.]

	Iron.	Phosphorus.
Across 150 feet, Pilot No. 1	58.98	0.16
Across 250 feet, Pilot No. 1	62.38	.217
Across 40 feet, Pilot No. 1	62.06	.163
Pilot No. 12	66.40	.072
Across 40 feet, Pilot No. 7	64.13	.434

There has been a small amount of pitting, trenching, and tunneling, but these amount only to scratches in the upper parts of the deposits.

DEPOSITS OF SIMILAR ORIGIN IN OTHER DISTRICTS.

Ores similar to those of the Iron Springs district, consisting principally of magnetite in veins (not magmatic segregations *in situ*), in igneous rocks or near the contact of igneous rocks and limestone or in both combinations, are known at many localities in western North America, as follows:

In Mexico, where nearly all the iron ores are of this character, their distribution and occurrence being summarized by Hill^a and by Aguilera.^b The Durango deposit is described in a number of papers.

In several localities in San Bernardino County, Cal.,^c and in the Redding quadrangle of northern California.^d

In Lyon County, Nev., and in several other localities in the Great Basin.^e

In Stevens County, northeastern Washington, Texada and Vancouver islands, British Columbia,^f and Kamloops, British Columbia.^g

At Fierro^h and Chupadera Mesa, New Mexico.ⁱ

In the Taylor Peak, White Pine, and Cebolla districts in Pitkin and Gunnison counties, Colo.^j

At Iron Mountain, Missouri.^k

This list of localities is far from complete and no attempt is made to cite all the publications concerning the different areas. It is the

^a Hill, R. T., The occurrence of hematite and magnetite in the United States, 1888, p. 112.

^b Aguilera, José G., The geographical and geological

Trans. Am. Inst. Min. Eng., vol. 32, 1902, pp. 503-507.

^c Lerch, C. K., Iron ores of the western United States, 1906, No. 25, 1906, pp. 194-200.

^d Miller, J. S., Iron ores of the Redding quadrangle, 1906, pp. 219-220.

^e Manuscript notes furnished authors.

^f Lerch, C. K., op. cit., pp. 195-196. Report of the Provincial Mineralogist, Dept. of Mines, 1906.

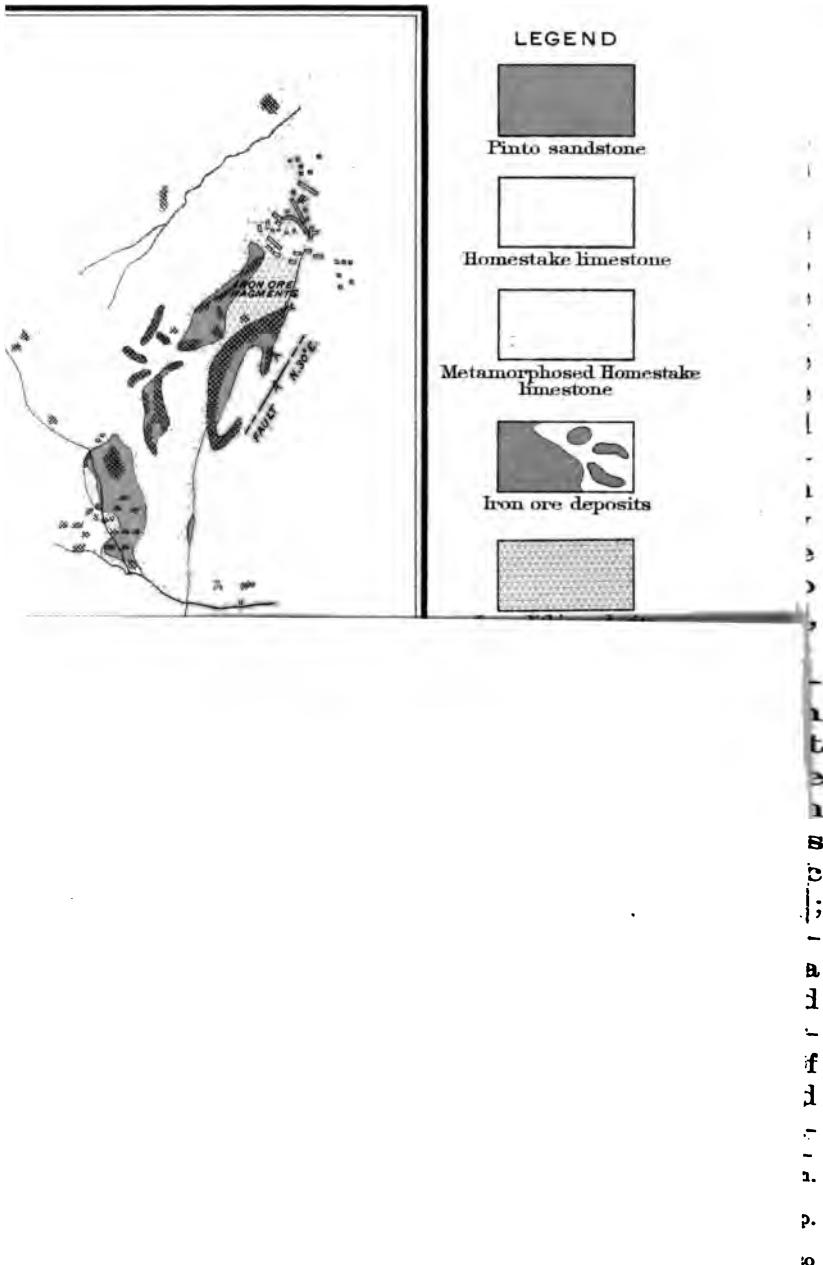
^g Manuscript furnished the authors by the Provincial Mineralogist, Dept. of Mines, 1906.

^h Keyes, Charles E., Iron deposits of the United States, 1906, p. 10.

ⁱ Manuscript notes, summaries of 1906.

^j Nason, Frank L., A report on the iron

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IRON ORES OF IRON SPRINGS DISTRICT, UTAH.

purpose simply to emphasize the widespread distribution of deposits of these types and to cite some of the descriptions.

From the fact that the ores of these districts have certain essential features in common, it does not necessarily follow that the origin of the ores has been the same for all. Certainly there has not been enough detailed work on the ores of many of the localities named to warrant final conclusions as to their origin. Nevertheless, the similarities in these deposits are such as to suggest similarity of origin as a guiding hypothesis for study, and such results as have been obtained to the present time tend strongly to support this hypothesis rather than to break it down.

Several deposits which have been examined personally by the writers or associates are unhesitatingly assigned an origin similar to that here presented for the Iron Springs district of Utah. These include the Taylor Peak and White Pine ores of Colorado, studied by Van Hise and Leith and mapped in detail by Harder and Ward; the Jebolla district of Colorado, examined by Van Hise and Leith; the Bull Valley district of Utah, examined by Leith and Harder; and certain of the deposits in northeastern Washington, Texada and Vancouver islands, the Kamloops district, British Columbia, and San Bernardino County, California, examined in reconnaissance by Leith. All of these ores, in hand specimen and slide, show intimate association with anhydrous silicates and have structural relations to wall rock essentially similar to those of the Iron Springs district, though differing from these in structural and lithologic details.

Among the men who have given particular attention to the economic geology of the west emphasis has been uniformly placed on the genetic association of ores and igneous rocks along contacts, but there has been lack of agreement as to the real significance of the association—as to whether the igneous rocks have contributed both solutions and ores, or only hot water which has leached the ores from the adjacent rocks, or only heat which has enabled meteoric waters to leach ores from the adjacent rocks and redeposit them; whether the solutions have been liquid or gaseous; what their direction of movement has been, etc. In recent years there has been a rapidly growing tendency to emphasize the importance of liquid and gaseous solutions coming directly from the igneous rocks and bringing the ores with them. In discussions of genetic classifications of ores by Lindgren,^a Weed,^b Spurr,^c and others, ore deposits developed along igneous contacts by "pneumatolytic after-action" find con-

^a Lindgren, Waldemar, The character and genesis of certain contact deposits: *Trans. Am. Inst. Min. Eng.*, vol. 31, 1902, pp. 226-244.

^b Weed, W. H., Ore deposits near igneous contacts: *Trans. Am. Inst. Min. Eng.*, vol. 33, 1903, pp. 15-746.

^c Spurr, J. E., A consideration of igneous rocks and their segregation or differentiation as related to the occurrence of ores: *Trans. Am. Inst. Min. Eng.*, vol. 33, 1903, pp. 288-340.

spicuous place. Iron-ore deposits have been included in this class largely because of the classic work of Vogt on the Christiania deposits. Individual deposits of western contact iron ores have not been specifically referred to this class because they have not been sufficiently known. The pneumatolytic origin of the Iron Springs ores now seems to be sufficiently well based and their similarity to other western contact iron ores sufficiently close to make it possible to assign a pneumatolytic origin to this general class of ores with some confidence.

The direct development of magnetite in pegmatitic veins is described by Spurr in the Georgetown quadrangle of Colorado. The case is conclusive, for magnetite crystals of considerable size are found in the interior of unaltered pegmatite veins.

Spencer^a reached the conclusion that certain of the New Jersey magnetites are essentially pegmatitic in their origin. In addition to the Christiana deposits, Vogt^b cites other European deposits^c which he regards as of the same origin. Beck^d does the same. Of interest also in this connection is the recent work of Stutzer^e on the ores, which he regards as dikes, of the Kirunavaara and Luossavaara districts in northern Sweden, and the still more recent work of Sjögren^f on the Scandinavian iron ores.

The prevalence of an iron cap or gossan above sulphide deposits in fissure veins or along the contact of igneous rocks and limestones is responsible for a widespread view that western iron ores of this occurrence will be found to grade down into sulphides; that the ores are the oxidized portions of sulphide veins which may have originated in the manner here outlined for the Iron Springs district; that the ores therefore have an ultimate igneous source to the same extent as the sulphide deposits, whatever this may be. Reasons are given on another page for the belief that the Iron Springs magnetite was deposited directly from hot solutions and not as an alteration product of sulphide, but that simultaneously there were deposited small and variable amounts of pyrite. So far as the writers know, there is no evidence of increase in sulphur content in depth in any of the ores of this class in the localities cited, beyond perhaps the first few inches or few feet, from which the sulphide, originally deposited with the

^a Spencer, A. C., Genesis of the magnetite deposits in Sussex county, N. J.: *Min. Mag.*, vol. 10, 1904, pp. 377-381.

^b Vogt, J. H. L., Problems in the geology of ore deposits: *Trans. Am. Inst. Min. Eng.*, vol. 31, 1902, pp. 125-169.

^c Northern Sweden, Kristiania district, southern Hungary, Island of Elba and Dieletti, France.

^d Beck, Richard, The nature of ore deposits, translated by W. H. Weed, 2 vols., New York, 1905, 685 pp.

^e Stutzer, O., Die Eisenerzlagerstätte Gellivare in Nordschweden: *Zeitschr. für prakt. Geol.*, bd. 14, No. 5, May, 1906, pp. 137-140; Die Eisenerzlagerstätten bei Kiruna: *Zeitschr. prakt. Geol.*, bd. 14, No. 3, March, 1906, pp. 65-71.

^f Sjögren, Hjalmar, The geological relations of the Scandinavian iron ores: *Trans. Am. Inst. Min. Eng.*, vol. 38, 1908, pp. 877-946.

ore, has been leached by weathering. It must be remembered, however, that no one of these deposits has been opened up sufficiently to demonstrate their character in depth.

The theory that iron ores at the contacts of igneous rocks and limestone have developed entirely by the action of meteoric waters from above, leaching ores from the adjacent rocks, has not been without supporters. This is the view held by Hill for the Durango deposit. The senior author presented this theory as possibly applicable to the Iron Springs deposits of Utah in an earlier publication. It would be entirely premature to exclude this hypothesis for all iron ores in fissure veins in igneous rocks or along their contacts with limestone, especially where these ores are largely limonite and apparently lack heavy anhydrous minerals, as in some of the deposits of northeastern Washington. It is usually where the ores are hard crystalline magnetites and hematites, intimately associated with the anhydrous silicates and adjacent to or within igneous rocks, that there is reasonable probability that the origin of the ores may be ascribed to the hot solutions coming from the igneous rocks.

STRUCTURAL DISSIMILARITIES OF THE IRON SPRINGS DEPOSITS TO OTHER CLASSES OF IRON-ORE DEPOSITS.

The structural features in which the iron-ore deposits of the Iron Springs district differ from ores of sedimentary origin, like the Lake Superior and Clinton ores, are obvious to all familiar with the great classes of iron-ore deposits, but for those who are not so familiar an elementary comparison may be of interest.

The Clinton hematites of Alabama and elsewhere are bedded deposits with all the stratigraphic and structural characteristics of sedimentary rocks. Given a bed, it may be expected to extend in strike and dip, thicken and thin, with about the same degree of uniformity as may be observed in other sedimentary layers, such as limestone or shale adjacent. Its structure also, as shown by strike and dip, is governed by the same laws as other deformed beds. It is thus frequently possible to determine with some certainty extensions of deposits for many thousands of feet. The Iron Springs deposits can not be followed or extensions calculated with any such certainty.

The Lake Superior iron-ore deposits are more or less irregular concentrations in a sedimentary "iron formation." The iron ores make up a very small per cent—less than 2—of the mass of the iron formation. The iron formation originally consisted of iron carbonate or iron silicate, and was altered to iron ore, ferruginous chert, or jaspilite, but retained its bedding. The structure and stratigraphy of the iron formation may be worked out as fully as for limestone or quartzite. Exploration is limited to the iron formation, and the presence of an

iron formation is regarded as a prerequisite for exploration for iron ore. The Iron Springs deposits lack an associated sedimentary iron formation to serve as a guide for exploration, though there are locally present lean phases of ores for which the term "iron formation," without genetic significance, might be appropriate. The deposits themselves in the Lake Superior region rest in structural basins which determine for each district certain uniformities and peculiarities of shape for the ore deposits for that district. For the Lake Superior region as a whole the variety of shapes of ore deposits is probably greater than that in the Iron Springs district, but the Iron Springs deposits probably have a shape and size which can be less safely predicted in advance of exploration than can those of the deposits of any one of the Lake Superior districts. They have, however, one considerable advantage in that they are largely exposed on the erosion surface, whereas the Lake Superior deposits are in great part covered by glacial drift.

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BULLETIN NO. 338 PL.VI



DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

THE PURCHASE OF COAL UNDER GOVERNMENT
AND COMMERCIAL SPECIFICATIONS ON THE
BASIS OF ITS HEATING VALUE

WITH ANALYSES OF COAL DELIVERED UNDER
GOVERNMENT CONTRACTS

BY

D. T. RANDALL



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THE PURCHASE OF COAL UNDER GOVERNMENT AND COMMERCIAL SPECIFICATIONS ON THE BASIS OF ITS HEATING VALUE.

By D. T. RANDALL.

INTRODUCTION.

The people of this country have been purchasing coal for years on the statement of the selling agent as to its quality, or on the reputation of the mine or district from which it was obtained. The farmers of the country show more business judgment in the purchase of fertilizer than do many manufacturers in buying coal, for the farmer demands a chemical analysis of the fertilizer before he accepts it.

Until recently there has been but little reliable information regarding the character of the coal supply of the United States. This fact was recognized in the establishment of the fuel-testing plant of the United States Geological Survey at St. Louis in 1904. Extended general investigations have been conducted at this plant and its successors and in the field, and in addition the technologic branch of the Survey has been charged with the duty of analyzing and testing the coals used by the Government.

The Government is a large purchaser of coal, reports from the various Departments indicating that nearly \$6,300,000 is expended each year for fuel. Some time ago the necessity for a more uniform standard in the purchase of coal became apparent and the plan of buying it on the basis of its heating value was introduced in a few Departments. Many of the large commercial consumers in the United States have been purchasing their coal on contracts of this nature for some time.

The present paper summarizes the information on this subject obtained by the Survey, including examples of specifications that are now in use and analyses of some of the coal purchased by the Government during the winter of 1906-7.

ADVANTAGES OF DEFINITE SPECIFICATIONS IN THE PURCHASE OF COAL.

Under the old plan of purchasing coal, when the consumer had cause or thought he had cause to find fault with the quality of the fuel he received, he was in many cases assured that it must be good because, like all the other coal sent him, it came from a mine with an established reputation. Such a state of affairs made it difficult to take advantage of the competition which usually results when a considerable number of bidders are asked to submit prices. The purchaser was afraid to buy from any but such dealers as he knew and trusted, because, although each dealer claimed that his coal was equal in quality to that of the others, yet if it did not prove to be satisfactory there was no standard for settlement or for cancellation of the contract. Many thousands of dollars' worth of coal are bought each year in this manner, but the purchasers would consider it ridiculous if they were asked to contract for a building with no specifications and simply on the agreement that it should be of a certain size and well constructed. Neither would they buy gold, silver, or even copper and iron ores on the mere information that they were mined at certain localities. All products of mines are now purchased to a great extent on the basis of their value as shown by chemical analysis. This is true of coal in only a small degree, but the number of contracts made on this basis is increasing every year.

The purchase of coal on a specification is as advantageous as a definite understanding regarding the quality and other features of any other product, or of a building operation or engineering project. The man who buys under a specification gets what he pays for and pays for what he gets.

When the bidder is allowed to specify the quality of the coal he proposes to furnish as determined by a chemical analysis, he is placed on a strictly competitive basis with other bidders. Such a procedure broadens the field for both the bidder and the purchaser. It makes the bidder's proposal, when accepted, a contract that specifies an established standard of quality. This furnishes a basis for settling disputes regarding the quality of the coal delivered and the price to be paid if the fuel is either better or poorer than has been guaranteed. If other coal must be substituted, as often happens, there is a standard for settlement. If the coal is uniformly poorer than the standard as specified there is a basis for cancellation of the contract.

The quality of coal from a given mine may vary from time to time through the failure of the miners to reject impurities. Sometimes different beds of coal are mined at the same time and the output is mixed. When there is need of further preparation, such as picking

slate and other impurities, or jigging or washing, a great deal depends on the care used in these processes. The mining companies are responsible in a large measure for variations in the grade of prepared coal. The purchase of coal under a contract on the basis of quality stimulates the operator to make a better preparation of the coal before it is shipped to market. An example of fluctuations in quality is furnished by the tables on pages 24-26, which show variations in the ash and British thermal units in coal delivered to some of the Government Departments at Washington.

It evidently will not be satisfactory to either the buyer or the seller to establish a standard for the coal unless this liability to variation is recognized and provision made for settlement when the coal is better or poorer than the standard. Experience with any method of buying coal shows that it will seldom be rejected when of poor quality, because of the difficulty, delay, and cost of removing it from the bins. The buyer is often confronted with the alternative of burning the coal delivered or going without fuel until more can be procured. Unless the coal is very bad it is usually expedient to use it and pay a smaller price. This is also more favorable to the contractor, as to remove the coal would be costly and it would not be satisfactory as fuel to any other customer.

VALUE OF COAL AS A FUEL.

The purpose of burning coal under boilers is to abstract the heat for use in developing power, in drying various materials, or in warming buildings. The most valuable coal, therefore, is that which gives up the most heat to the boiler for a given weight burned.

Coal is now burned for power purposes in gas producers and boiler furnaces. For coals and lignites high in moisture or high in ash, the gas producer, used in connection with a gas engine, is best adapted to develop power. But for the generation of steam, which can be used for heating as well as for power purposes, a more convenient method is to burn the coal in a specially constructed furnace under a boiler.

The aim in the purchase of coal for any power plant should be to obtain a fuel which will produce a horsepower for the least cost, all things being considered, such as the equipment, the price of coal, and the cost of labor and repairs. Experiments have been made which seem to indicate that almost any fuel may be burned with reasonable efficiency in a properly designed apparatus. The recognized requirements are as follows:

A supply of fuel fed to the furnace as uniformly and continuously as possible.

An air supply slightly in excess of the theoretical amount required for complete combustion.

A sufficiently high temperature to ignite the gases which are driven off from the fuel.

A complete mixture of these gases with the air supplied before they reach a cooling surface, such as the shell or tubes of a boiler.

Some of the factors which may influence the commercial results obtained in a boiler are the cost of the coal, as determined by price and heating value; care in firing; design of the furnace and boiler setting, size of grate, etc.; formation of excessive amounts of clinkers and ash; draft available; size of the coal (uniformity of size is desirable).

The value of a coal is indicated by the number of heat units it contains. This heating value is expressed in terms of British thermal units ^a (abbreviated B. t. u.) per pound of coal, and is determined by means of a special apparatus called a calorimeter.

When coal is mined it contains moisture to a greater or less extent. It is exposed to the air in shipment and may either dry out or be drenched by rain. The moisture in the coal delivered is worthless to the purchaser, and really costs him a considerable amount in freight and cartage, and in the loss of the heat absorbed during its evaporation in the furnace. If all coal had the same proportion of moisture, or if the moisture in coal delivered by a given dealer was constant in amount, the purchaser's problem, so far as this factor is concerned, would be simplified. Under present conditions the moisture is an important element in the valuation of a ton of coal. It is evidently necessary to consider the coal just as it is received in order to determine its value to the consumer, but chemical reports should be made on the basis of both the "dry coal" and the "coal as received." The dry-coal basis is convenient for comparing several coals in regard to the relation of each element to the others; this is important because the moisture in the same coal varies from day to day. The dry-coal basis is also convenient for comparing the performance of boilers when burning the same or similar coals. Of several coals having a similar composition, the one which has the least moisture and the least ash will generate the most steam when burned under a boiler.

Ash is made up of earthy matter and other impurities which will not burn. In commercial coals its proportion may range from 4 to 25 per cent. Coals containing small percentages of ash are most valuable, not only because of their correspondingly higher heating capacity, but because there is less resistance to the free and uniform distribution of air through the bed of coal. The labor and cost of managing the fires and of handling the ashes are also correspondingly

^a The British thermal unit is the amount of heat required to raise the temperature of 1 pound of water 1° Fahrenheit.

less and are items to be considered in the choice of a coal. With the ordinary furnace equipment there may be a considerable loss of efficiency and capacity through a large percentage of ash. It has been found that with some kinds of equipment, as the ash increases there is a decided drop in both efficiency and capacity. In some experiments made to determine the influence of excessive amounts of ash, coal containing as high as 40 per cent would generate no steam when fired on a chain grate, and therefore the efficiency and capacity of the plant would be zero.^a Such coal would not only be worthless, but involve a direct expense, due to the cost of handling it. Whether the result would be similar with equipment other than a chain grate has not yet been determined. However, coals so high in ash that they are unsuited to boiler furnaces can be utilized in gas producers.

The volatile part of coal as shown by the analysis may in some coals be all combustible, but it generally contains some inert matter. This varies in different coal deposits and makes it impossible to determine the heating value of the coal from the proximate analysis alone. Moreover, not all coals having the same proportion of volatile matter behave alike in the furnace. It is important to know both the chemical composition and the British thermal units in order to determine the value of one coal as compared with another for the same purpose.

Of two coals of different character, the one which contains the higher proportion of fixed carbon is most easily burned so as to give the maximum efficiency. However, if the coal containing the higher volatile matter is properly burned in a suitably designed furnace, it may be made equally efficient.

Sulphur may be present in the free state, or, as is more commonly the case, in combination with iron or other elements. Other impurities with sulphur often form a clinker which shuts out the air and increases the labor of handling the furnaces. It is possible, however, to burn coals containing up to 5 per cent of sulphur without particular difficulty from clinkers. A little steam introduced under the grate will relieve much of the trouble. Clinker may be due to other causes than sulphur, as any constituents of the ash which are easily fusible may produce it. There is need of further investigation to determine the influence of sulphur and the elements which comprise the ash on furnace fires and combustion.

The size of the coal influences the capacity of any given equipment, owing to its effect on the draft. With a poor draft fine coal can not be burned in sufficient quantities to maintain the rated capacity. If thin fires are resorted to, the efficiency is usually lowered as a result of an excessive supply of air through holes in the fire. As a

^a Abbott, W. L., Some characteristics of coal as affecting performance with steam boilers, a paper read before the Western Society of Engineers, Chicago, Ill.

rule, when dust and very fine coal are fed into the furnace they either check the flow of air or are taken up by the draft and after being only partly burned are deposited back of the bridge wall or pass up the stack, to the annoyance of the people in the vicinity of the plant. If this dust is completely burned in passing through the furnace there is of course no loss of fuel. It has been found that coal of a uniform size is most satisfactory, as it does not pack so closely as a mixture of sizes.

In general it may be said that in any market the coal obtainable at the lowest price is the most economical, provided the furnace equipment is suitable. If the furnace is not so designed as to permit the use of the cheaper coal, it should be changed.

The results of tests tend to show that, other conditions being equal, coals of similar composition are of value in proportion to the British thermal units in the coal as received—a basis on which, indeed, all coals may be valued approximately. It should be remembered, however, that the value of a coal for any particular plant is influenced by the fact that all furnaces are not equally suitable for burning the many grades of coal. Aside from this factor, coals may be compared in terms of the British thermal units obtained for 1 cent, or on the cost per million heat units.

In the purchase of coal, then, attention should be given to the character of the furnace equipment and the load; the character of coal best suited to the plant conditions; the number of heat units obtainable for a unit price; the cost of handling the coal and ash; and the possibility of burning the coal without smoke or other objectionable features.

SPECIFICATIONS IN USE.

As the result of a letter from President Roosevelt to the national advisory board on fuels and structural materials, calling attention to the need of a uniform and efficient basis for the purchase of the Government fuel supply, the following specification was drafted by engineers in the employ of the Government and approved by this board in March, 1907:

SPECIFICATIONS AND PROPOSALS FOR SUPPLYING COAL.

United States _____, 190____

PROPOSAL.

Sealed proposals will be received at this office until 2 o'clock p. m., _____, 190____, for supplying coal to the United States _____ building at _____ as follows:

The quantity of coal stated above is based upon the previous annual consumption, and proposals must be made upon the basis of a delivery of 10 per cent more or less than this amount, subject to the actual requirements of the service.

Proposals must be made on this form, and include all expenses incident to the delivery and stowage of the coal, which must be delivered in such quantities and at such times within the fiscal year ending June 30, 190--, as may be required.

Proposals must be accompanied by a deposit (certified check, when practicable, in favor of _____) amounting to 10 per cent of the aggregate amount of the bid submitted, as a guaranty that it is bona fide. Deposits will be returned to unsuccessful bidders immediately after award has been made, but the deposit of the successful bidder will be retained until after the coal shall have been delivered and final settlement made therefor, as security for the faithful performance of the terms of the contract, with the understanding that the whole or a part thereof may be used to liquidate the value of any deficiencies in quality or delivery that may arise under the terms of the contract.

When the amount of the contract exceeds \$10,000, a bond may be executed in the sum of 25 per cent of the contract amount, and in this case the deposit or certified check submitted with the proposal will be returned after approval of the bond.

The bids will be opened in the presence of the bidders, their representatives, or such of them as may attend, at the time and place above specified.

In determining the award of the contract, consideration will be given to the quality of the coal offered by the bidder, as well as the price per ton, and should it appear to be to the best interests of the Government to award the contract for supplying coal at a price higher than that named in lower bid or bids received, the award will be so made.

The right to reject any or all bids and to waive defects is expressly reserved by the Government.

DESCRIPTION OF COAL DESIRED.^a

Bids are desired on coal described as follows:

Coals containing more than the following percentages, based upon dry coal, will not be considered:

Ash -----	-----per cent.
Volatile matter -----	-----per cent.
Sulphur -----	-----per cent.
Dust and fine coal as delivered at point of consumption ^b -----	-----per cent.

DELIVERY.

The coal shall be delivered in such quantities and at such times as the Government may direct.

^a This information will be given by the Government as may be determined by boiler and furnace equipment, operating conditions, and the local market.

^b All coal which will pass through a $\frac{1}{4}$ -inch round-hole screen.

In this connection it may be stated that all the available storage capacity of the coal bunkers will be placed at the disposal of the contractor to facilitate delivery of coal under favorable conditions.

After verbal or written notice has been given to deliver coal under this contract, a further notice may be served in writing upon the contractor to make delivery of the coal so ordered within twenty-four hours after receipt of said second notice.

Should the contractor, for any reason, fail to comply with the second request, the Government will be at liberty to buy coal in the open market, and to charge against the contractor any excess in price of coal so purchased over the contract price.

SAMPLING.

Samples of the coal delivered will be taken by a representative of the Government.

In all cases where it is practicable, the coal will be sampled at the time it is being delivered to the building. In case of small deliveries, it may be necessary to take these samples from the yards or bins. The sample taken will in no case be less than the total of 100 pounds, to be selected proportionally from the lumps and fine coal, in order that it will in every respect truly represent the quantity of coal under consideration.

In order to minimize the loss in the original moisture content the gross sample will be pulverized as rapidly as possible until none of the fragments exceed one-half inch in diameter. The fine coal will then be mixed thoroughly and divided into four equal parts. Opposite quarters will be thrown out, and the remaining portions thoroughly mixed and again quartered, throwing out opposite quarters as before. This process will be continued as rapidly as possible until the final sample is reduced to such amount that all of the final sample thus obtained will be contained in the shipping can or jar and sealed air-tight.

The sample will then be forwarded to-----

If desired by the coal contractor, permission will be given to him, or his representative, to be present and witness the quartering and preparation of the final sample to be forwarded to the Government laboratories.

Immediately on receipt of the sample, it will be analyzed and tested by the Government, following the method adopted by the American Chemical Society, and using a bomb calorimeter. A copy of the result will be mailed to the contractor upon the completion thereof.

CAUSES FOR REJECTION.

A contract entered into under the terms of this specification shall not be binding if, as the result of a practical service test of reasonable duration, the coal fails to give satisfactory results owing to excessive clinkering or to a prohibitive amount of smoke.

It is understood that the coal delivered during the year will be of the same character as that specified by the contractor. It should, therefore, be supplied, as nearly as possible, from the same mine or group of mines.

Coal containing percentages of volatile matter, sulphur, and dust higher than the limits indicated on page 2 and coal containing a percentage of ash in excess of the maximum limits indicated in the following table will be subject to rejection.

In the case of coal which has been delivered and used for trial, or which has been consumed or remains on the premises at the time of the determination of

its quality, payment will be made therefor at a reduced price, computed under the terms of this specification.

Occasional deliveries containing ash up to the percentage indicated in the column of "Maximum limits for ash," on page 4, may be accepted. Frequent or continued failure to maintain the standard established by the contractor, however, will be considered sufficient cause for cancellation of the contract.

PRICE AND PAYMENT.^a

Payment will be made on the basis of the price named in the proposal for the coal specified therein, corrected for variations in heating value and ash, as shown by analysis, above and below the standard established by contractor in this proposal. For example, if the coal contains 2 per cent, more or less, British thermal units than the established standard, the price will be increased or decreased 2 per cent accordingly.

The price will also be further corrected for the percentages of ash. For all coal which by analysis contains less ash than that established in this proposal a premium of 1 cent per ton for each whole per cent less ash will be paid. An increase in the ash content of 2 per cent over the standard established by contractor will be tolerated without exacting a penalty for the excess of ash. When such excess exceeds 2 per cent above the standard established, deductions will be made from price paid per ton in accordance with following table:

Ash as established in proposal (per cent).	No deduction for limits below.	Cents per ton to be deducted.						Maximum limits for ash.	
		2	4	7	12	18	25		
		Percentages of ash in dry coal.							
5.....	7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	12
6.....	8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	13
7.....	9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	14
8.....	10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	14
9.....	11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	15
10.....	12	12-13	13-14	14-15	15-16	16-17	17-18	-----	16
11.....	13	13-14	14-15	15-16	16-17	17-18	18-19	-----	16
12.....	14	14-15	15-16	16-17	17-18	18-19	19-20	-----	17
13.....	15	15-16	16-17	17-18	18-19	19-20	20-21	-----	18
14.....	16	16-17	17-18	18-19	19-20	20-21	21-22	-----	19
15.....	17	17-18	18-19	19-20	20-21	21-22	-----	-----	19
16.....	18	18-19	19-20	20-21	21-22	22-23	-----	-----	20
17.....	19	19-20	20-21	21-22	22-23	-----	-----	-----	21
18.....	20	20-21	21-22	22-23	-----	-----	-----	-----	22

Proposals to receive consideration must be submitted upon this form and contain all of the information requested.

, 190--

The undersigned hereby agree to furnish to the U. S. ----- building at -----, the coal described, in tons of 2,240 pounds

^a The economic value of a fuel is affected by the actual amount of combustible matter it contains, as determined by its heating value shown in British thermal units per pound of fuel, and also by other factors, among which is its ash content. The ash content not only lowers the heating value and decreases the capacity of the furnace, but also materially increases the cost of handling the coal, the labor of firing, and the cost of the removal of ashes, etc.

each and in quantity 10 per cent more or less than that stated on page 1, as may be required during the fiscal year ending June 30, 190_____, in strict accordance with this specification; the coal to be delivered in such quantities and at such times as the Government may direct.

	Item No.	Item No.	Item No.			
<i>Description.</i>						
Commercial name.....						
Name of mine.....						
Location of mine.....						
Name of coal bed.....						
Size of coal (if coal is screened):						
Coal to pass through openings.....	inches	round.	inches	round.	inches	round.
Coal to pass over openings.....	inches	square.	inches	square.	inches	square.
Coal to pass through openings.....	inches	bar.	inches	bar.	inches	bar.
<i>Data to establish a basis for payment.</i>						
Per cent of ash in dry coal (method of American Chemical Society).						
British thermal units in coal as delivered.						
Price per ton (2,240 pounds).						

It is important that the above information does not establish a higher standard than can be actually maintained under the terms of the contract; and in this connection it should be noted that the small samples taken from the mine are invariably of higher quality than the coal actually delivered therefrom. It is evident, therefore, that it will be to the best interests of the contractor to furnish a correct description with average values of the coal offered, as a failure to maintain the standard established by contractor will result in deductions from the contract price, and may cause a cancellation of the contract, while deliveries of a coal of higher grade than quoted will be paid for at an increased price.

Signature.....

Address.....

Name of corporation.....

Name of president.....

Name of secretary.....

Under what law (State) corporation is organized.....

As will be seen from the foregoing specification, the bidder is not required to submit a sample of his coal, but is expected to name a standard of British thermal units in the coal as it is to be delivered. This value is made the basis for purchase, because a correction is thus made for the amount of moisture in the coal. It should be noted that this value will in all cases be lower than the British thermal units in the dry coal, which is usually given in connection with the coal analysis. The percentage of ash is also specified, as it is a factor in the successful burning of the coal on the grate and as it involves an expense for removal from the premises.

If the dealer is not fairly familiar with the value of his coal, it may then be arranged to have him submit a properly selected sample with his bid, this sample to be analyzed by the Government and the results used as a standard in the contract. It is preferred, however, that the bidder use his own values.

The following circular letter was issued by the Treasury Department in connection with the Government specification, for the information of dealers desiring to bid on coals for public buildings, such

as mints, custom-houses, and post-offices located in all parts of the United States:

TREASURY DEPARTMENT, OFFICE OF THE SECRETARY.

Washington, March 27, 1907.

SIR: The accompanying specifications for coal are intended to give a clear description of the coal desired by the Government, and to secure a definite statement of the quality of coal offered by the bidder, with a view to using such statement as a basis for payment in connection with the stated price per ton. The plan is not new in its essential features, as it is an extension of a system already in force in the larger United States public buildings, and is similar to that employed by a number of private consumers.

What is desired is not necessarily the cheapest or the highest grade of coal per se, but the coal which will insure the greatest net economy in plant operation. In view of these facts the description of the coal inserted by the Government on page 2 of the accompanying specifications will receive careful consideration as the boiler and furnace conditions require. It is not expected that all deliveries will be absolutely uniform or agree exactly with the standard established by the contractor, but it is necessary that all deliveries shall be within the limits set by the Government.

The limits are wide enough to permit the use of the output of any mine or group of mines provided proper care is exercised in mining and picking out slate, bone, etc. With these points in mind it is only necessary for the bidder to select coal for each proposal which will meet the description given and permit deliveries within the limits set. The standard established by the contractor should be such as to require the least correction applying to deliveries for variation in heat units and ash from values established.

It is believed that the enforcement of the provisions of the specifications will operate equitably both with respect to the Government and to the contractor, and will guarantee adequate protection to each. Many coal dealers have already signified their willingness to furnish coal on this basis, and have commended as well as indorsed the method.

The application of this system will not only enable the award of a contract to be made in an equitable manner, but will also remove many of the usual causes for dispute as to the character and quality of the coal subsequently delivered, and provide a satisfactory basis for the correction of payments for differences in quality in favor of the party in whose interest it is due.

The system of sampling, analyzing, and testing coal delivered under the Government contracts will be under the supervision of the fuel-testing division of the Geological Survey, in order to insure reliability and impartiality.

The heating value expressed in British thermal units of coal containing approximately the same percentage of ash is essentially a direct measure of the actual value to the purchaser, and for this reason the specifications provide for an adjustment of payment in direct proportion to the variation in heat units in the coal as received. As the coal is weighed when delivered and the payments are based also upon the price per ton, it is necessary to determine the heating value of the coal in the condition in which it is received, containing whatever moisture may be present at the time.

A further correction in payment will be made for variation of the ash in dry coal in order to take account of the cost of handling additional fuel and ash and its effect on the capacity of the boiler and furnace.

Respectfully,

A. E. STATTER,
Assistant Secretary.

On account of lack of information among the dealers in anthracite coal as to the heating value of the several sizes and kinds used by the Government, a number of contracts were let on the basis of the ash in dry coal. For the city of Washington these were worded in the same way as the regular specification, except the section relating to price and payment, which was as follows:

PRICE AND PAYMENT.

Payment will be made on the basis of the price named in the proposal for the coal specified, corrected for variations in ash as shown by analysis, above and below the standard established by the contractor.

For an increase or decrease up to 2 per cent in the ash content above or below the standard no correction will be made in the price. When the variation exceeds this allowance above or below the standard, corrections will be made in the price as follows:

For furnace, egg, stove, and chestnut sizes of coal, variations from the standard percentage of ash exceeding 2 and less than 2.5 above and below will result in the deduction or addition of 15 cents per ton. For each additional one-half of 1 per cent, or fraction thereof, 3 cents more per ton will be deducted or added.

For pea coal, variations from the standard percentage of ash exceeding 2 and less than 2.5 above and below will result in the deduction or addition of 10 cents per ton. For each additional one-half of 1 per cent, or fraction thereof, 2½ cents more per ton will be deducted or added.

For buckwheat and screenings, variations from the standard percentage of ash exceeding 2 and less than 2.5 above and below will result in the deduction or addition of 8 cents per ton. For each additional one-half of 1 per cent, or fraction thereof, 2 cents more per ton will be deducted or added.

The following specification is used by a few firms in Baltimore, Md.:

SPECIFICATIONS AND INFORMATION CONCERNING SUPPLY OF COAL FOR -----

Caution.—Bidders are directed to familiarize themselves with the storage facilities and local conditions, affecting the deliveries of coal, existing at the power house.

Method of determining quantity and quality.—Weights are subject to check either by measurement or by company scales. Any deficiency will be deducted from and any excess added to the bill.

Sampling will be done by a representative of the company and contractor may have a representative present.

Sample will be taken from each delivery and kept in hermetically sealed jars.

Detail of specifications.—Coal will be semibituminous and run-of-mine. It shall be dry, well picked, and free from excessive amounts of slate, pyrites, and dirt of any kind and shall have the following composition: Moisture, not over 1 per cent; volatile carbon, not over 20 per cent; ash, not over 7 per cent; sulphur, not over 1 per cent.

ADJUSTMENTS.

Additions.—If the coal has less than 1 per cent moisture, the deficit per cent less than 1 per cent will be added to the bill. If the coal has less than 20 per cent volatile carbon, the deficit per cent less than 20 per cent will be multiplied by 2 and added to the bill. If the coal has less than 7 per cent ash, the deficit per cent less than 7 per cent will be multiplied by 3 and added to the bill.

Deductions.—If the coal contains more than 1 per cent moisture, the excess per cent above 1 per cent will be deducted from the bill. If the coal contains more than 20 per cent volatile carbon, the excess per cent above 20 per cent will be multiplied by 2 and deducted from the bill. If the coal contains more than 7 per cent ash, the excess per cent above 7 per cent will be multiplied by 3 and deducted from the bill.

The following are the essential features of the contracts on which a Chicago company is said to purchase and inspect nearly 1,000,000 tons of coal for its clients in Chicago, Indianapolis, Minneapolis, St. Louis, and other cities:

I. The company agrees to furnish and deliver to the consumer _____ at such times and in such quantities as ordered by the consumer for consumption at said premises during the term hereof, at the consumer's option, either or all of the kinds of coal described below; said coals to average the following assays:

Kind of coal			
Of size passing through screen having circular perforations in diameter	..... inches	..... inches	..... inches
Of size passing over a screen having circular perforations in diameter	..... inches	..... inches	..... inches
Per cent of moisture in coal as delivered			
Per cent of ash in coal as delivered			
British thermal units per pound of dry coal			
From following county			
From following State			

Coal of the above respective descriptions and specified assays (not average assays) to be hereinafter known as the contract grade of the respective kinds.

II. The consumer agrees to purchase from the company all the coal required for consumption at said premises during the term of said contract, except as set forth in Paragraph III below, and to pay the company for each ton of 2,000 pounds avoirdupois of coal delivered and accepted in accordance with all the terms of this contract at the following contract rate per ton for coal of each respective contract grade, at which rates the company will deliver the following respective numbers of British thermal units for 1 cent, the contract guaranty:

Kind of coal.	Contract rate per ton.	Contract guaranty.
.....	\$.....	equal to net B. t. u. for 1 cent.
.....	\$.....	equal to net B. t. u. for 1 cent.
.....	\$.....	equal to net B. t. u. for 1 cent.

Said net British thermal units for 1 cent being in each case determined as follows: Multiply the number of British thermal units per pound of dry coal by the per cent of moisture (expressed in decimals), subtract the product so found from the number of British thermal units per pound of dry coal, multiply the remainder by 2,000, and divide this product by the contract rate per ton (expressed in cents) plus one-half of the ash percentage (expressed as cents).

III. It is provided that the consumer may purchase for consumption at said premises coal other than herein contracted for, for test purposes, it being un-

derstood that the total of such coal so purchased shall not exceed 5 per cent of the total consumption during the term of this contract.

IV. It is understood that the company may deliver coal hereunder containing as high as 3 per cent more ash and as high as 3 per cent more moisture and as low as 500 fewer British thermal units per pound dry than specified above for contract grades.

V. Should any coal delivered hereunder contain more than the per cent of ash or moisture or fewer than the number of British thermal units per pound dry allowed under Paragraph IV hereof, the consumer may, at its option, either accept or reject same.

VI. All coal accepted hereunder shall be paid for monthly at a price per ton determined by taking the average of the delivered values obtained from the analyses of all the samples taken during that month, said delivered value in each case being obtained as follows: Multiply the number of British thermal units delivered per pound of dry coal by the per cent of moisture delivered (expressed in decimals), subtract the product so found from the number of British thermal units delivered per pound of dry coal, multiply the remainder by 2,000, divide this product by the contract guaranty, and from this quotient (expressed as dollars and cents) subtract one-half of the ash percentage delivered (expressed as cents).

In Cleveland, Ohio, coal is purchased for the waterworks on the basis of its heating value. The standard agreed upon is 13,624 British thermal units and was established as the result of analysis and tests made on a sample furnished by the dealer.

The following are the essential features of the specifications used by the Interborough Rapid Transit Company of New York in purchasing about 30,000 tons of coal each month for use in its plants, which are among the largest in the United States:

PRELIMINARY SPECIFICATIONS FOR BITUMINOUS COAL FOR THE INTERBOROUGH RAPID TRANSIT COMPANY.

Coal must be a good steam, caking, run-of-mine, bituminous coal free from all dirt and excessive dust, a dry sample of which will approximate the company's standard in heat value and analysis, as follows: Carbon, 71; volatile matter, 20; ash, 9; British thermal units, 14,100; sulphur, 1.50.

A small quantity of coal will be taken from each weighing hopper just before the hopper is dumped while the lighter is being unloaded. These quantities will be thrown into a receptacle provided for the purpose, and when the lighter is empty the contents of the receptacle will be thoroughly mixed, and a sample of this mixture will be taken for chemical analysis. This average sample of coal will be labeled and held for one week after the unloading of the lighter. The sample taken from the mixture for test will be analyzed as soon as possible after being taken. No other sample will be recognized.

Tests of sample taken from average sample will be made by the company's chemist under the supervision of the superintendent. Should the contractor question the results of the company's test (a copy of which will be mailed to him), the company will, if requested by the contractor within three days after copy of test has been mailed to him, forward sufficient quantity of the average sample taken from each weighing hopper to any laboratory in the city of New York which may be agreed upon by the superintendent and the contractor, and have said sample analyzed by it, and the results obtained from this second test will be considered as final and conclusive. In case the disputed values, as ob-

tained in the company's test, shall be found by the second test to be 2 per cent or less in error, then the cost of said second test shall be borne by the contractor; but if the disputed values shall be found to be more than 2 per cent in error, then the cost of said second test shall be borne by the company.

Should there be no question raised by the contractor within the three days specified, as to the values of the first analysis, the average sample of coal will be destroyed at the end of seven days from date of discharge of coal from lighter. Should a second test be made of coal taken from any lighter as herein provided, then any penalties to be made as set forth in paragraph under "Penalties" will be based on the results as obtained from the second test.

The price to be paid by the company per ton per lighter of coal will be based on a table of heat values for excess or deficiency of its standard, but subject to deductions as given in the section under "Penalized coal," including excess of ash, volatile matter, sulphur, or dust, or less than the minimum amount required to be contained in any lighter, for coal which shows results less than the company's standard.

Premiums or deductions are based on a rate of 1 cent per ton for a variation of 50 British thermal units per pound of coal, as indicated in a table a few items of which are given below:

Table for B. t. u. values.

For coal in any lighter which is found by test to contain, per pound of dry coal, from—

15,501 and above	28 cents per ton above standard.
15,101 to 15,150, both inclusive	20 cents per ton above standard.
14,601 to 14,650, both inclusive	10 cents per ton above standard.
14,101 to 14,150, both inclusive	Standard.
13,601 to 13,650, both inclusive	10 cents per ton below standard.
13,101 to 13,150, both inclusive	20 cents per ton below standard.
12,101 to 12,150, both inclusive	40 cents per ton below standard.

No lighter of coal will be accepted which, by trial, in the judgment of the superintendent, contains an excessive amount of dry coal dust. The decision of the superintendent will be final in this respect. Coal taken from such lighter for trial will be subject to the special deduction set forth under "Penalized coal," but paid for in all other respects as herein provided.

Coal which is shown by analysis to contain less than 20 per cent of volatile matter, 9 per cent of ash, or 1.50 per cent of sulphur, will be accepted without a deduction from the bidder's price, plus or minus an amount for excess or deficiency of British thermal unit value, as herein provided. Where the analysis gives amounts for any or all elements in excess of these quantities, deductions will be made from the bidder's price in accordance with the tables of values of volatile matter, ash, and sulphur below given, plus or minus the amount for excess or deficiency of the standard British thermal unit value, in addition to any other deductions which may be made as herein provided.

Table of deductions for volatile matter.

For coal in any lighter which is found by test to contain, per pound of dry coal—

Over 20 per cent and less than 21 per cent	2 cents per ton.
* * * * *	* * *
Over 22.5 per cent and less than 23 per cent	12 cents per ton.
* * * * *	* * *
24 per cent and over	18 cents per ton.

This table is made for a difference of each one-half of 1 per cent and the deductions are at the rate of 4 cents for each 1 per cent of volatile matter.

Table of deductions for ash.

For coal in any lighter which is found by test to contain, per pound of dry coal—

Over 9 per cent and less than 9.5 per cent-----	2 cents per ton.
* * * * *	*
Over 11.5 per cent and less than 12-----	12 cents per ton.
* * * * *	*
13.5 per cent and over-----	23 cents per ton.

This table is made for each difference of one-half of 1 per cent and at the rate of 4 cents for each 1 per cent increase in the ash.

Table of deductions for sulphur.

For coal in any lighter which is found by test to contain, per pound of dry coal—

Over 1.50 per cent and less than 1.75 per cent-----	6 cents per ton.
* * * * *	*
Over 2 per cent and less than 2.25 per cent-----	10 cents per ton.
* * * * *	*

2.50 and over----- 20 cents per ton.

This table is made out for each difference of one-fourth of 1 per cent and at a diminishing rate.

Should any lighter of coal delivered at the company's docks contain less than 700 tons, a deduction of 7 cents per ton will be made from the price as determined by the British thermal unit value and analysis, in addition to any other penalty provided for herein. Should any lighter of coal delivered at the company's docks be rejected by the superintendent on account of excessive amount of coal dust, then a deduction of 25 cents per ton will be made from the price as determined by the British thermal unit value and analysis, for the coal taken from said lighter, in addition to any other penalty which may be made as herein provided. Should any lighter of coal be delivered in other than self-trimming lighters as herein provided, a deduction of 7 cents per ton will be made from the price as determined by the British thermal unit value and analysis, exclusive of any other penalty which may be made as herein provided.

The contractor's bill of lading will be checked by the company's scales. Should there be a deficiency of 1 per cent or more between the bill of lading and the company's weights, then the company's weights will be taken as correct.

When the contractor has been notified by the company to deliver coal under this contract, a further notice may be given requiring the contractor to make delivery of the coal so ordered within twelve hours after the receipt of said second notice. Should the contractor, for any reason, fail to deliver the coal so ordered within twelve hours after the receipt of said second notice and in accordance with the requirements therein as to place of delivery, the company shall be at liberty to buy coal in the open market, and the contractor will make good to the company any difference there may be between the price paid by the company for said coal in open market and the price the company would have paid to the contractor had the coal been delivered by it in accordance with

the requirements of said notices from the company, or said difference may be deducted from any money then due or thereafter to become due to the contractor under the contract to be entered into.

METHODS OF SAMPLING AND TESTING.

In connection with the Survey's study of the coal deposits of the country and the best methods to prevent waste in mining and utilizing the coal supply, trained inspectors have visited nearly 300 mines in 23 States, taking two or more samples from each mine. A study of the analyses of these samples and of samples taken from cars shipped from 175 of the same mines shows that the mine sample is in most instances better than the average of the coal as shipped in cars. On the average the coal delivered contains about one-third more ash than the mine sample taken in accordance with the instructions to the miners regarding the rejection of slate and impurities. This difference is due to the failure of the miners to follow these instructions in getting out coal for shipment. The samples collected by the Government inspectors from the mines almost invariably show a higher moisture content than is usually obtained in commercial sampling, because of the precaution taken to have the sample represent the coal in the mine.*

Mine samples when properly taken indicate the general character of the coal and enable one to judge of its probable value for any definite purpose.

Samples taken from the cars should not be limited to a few shovelfuls of coal from the top of the car, because the heavier pieces gradually work down toward the bottom. Some samples taken at the bottom of a car have shown as much as 8 per cent more ash than the coal at the top. The moisture also may vary from top to bottom, depending on the weather. The only way to get a fair sample is to take a number of shovelfuls of coal from various points in the car, so as to procure a representative portion of the coal from top to bottom and from end to end.

Bituminous coal when exposed to the air gradually depreciates in heating value, owing to losses of volatile matter, but aside from this loss there should be the same total number of heat units in a car of coal when it reaches its destination as when it started. If rain falls on the coal it will become heavier and a greater number of pounds will be delivered, but each pound will have a correspondingly lower heat value. On the other hand, if the weather is fair and the coal dries out on the way, it will weigh less and the heating value of each pound will be correspondingly higher. In other words, under a specification such as is used by the Government, neither the dealer

* A description of the method of mine sampling is given in Bull. U. S. Geol. Survey No. 290, 1906, pp. 17-18. See also Bull. No. 316, 1907, pp. 486-517.

nor the purchaser will gain or lose by change in the moisture content of the coal between the time it is weighed at the mine and the time it is weighed on delivery. The price per ton will be correspondingly lower if the coal is wet and higher if the coal is dry.

In order to determine the maximum variation in moisture in several sizes of anthracite coal the following experiments were made: The coal was soaked in water to allow it to absorb as much moisture as possible, the result representing the extreme conditions due to rains or other causes. Each sample was then weighed and allowed to dry in a room exposed to the air. When this sample ceased to lose moisture it was assumed to be air dried, which represents the condition of least moisture to be expected in a delivery of coal. The results are summarized in the following table:

Experiments to determine possible variations of moisture in anthracite coal during shipment.

	Furnace.	Pea.	Buck-wheat.
Number of samples used in experiment.....	13	10	12
Number of hours dried in air at ordinary room temperature.....	0.5 to 24	24	24
Total moisture in thoroughly wet coal.....per cent.	5.12	5.74	8.44
Moisture in air-dried samples.....do.....	3.58	1.84	2.24
Loss of moisture.....do.....	.73 to 1.54	3.1 to 3.9	4.5 to 6.2
Percentage of maximum variation in moisture from wet to air-dried coal.....	30	68	74

The air-dried anthracite still contains from 1.8 to 3.6 per cent of moisture. Moisture in air-dried coal varies with the weather, just as it does in wood.

The moisture in air-dried bituminous coals depends on the character of the coal. It is about 1 per cent in West Virginia coal and about 7 per cent in Illinois coal. The moisture in the same Illinois coal delivered may range from 7 to 17 per cent.

Owing to these variations some method should be used to correct for the difference in moisture in coals of different character.

The following suggestions are presented for the guidance of those who wish to send samples to a laboratory for analysis:

If samples are taken at the buildings as the coal is delivered, it will usually be satisfactory to take one shovelful of coal from each third or fifth wagonload, the load being selected without the knowledge of the driver. It must be kept in mind that the main object is to obtain a portion of coal which represents as nearly as possible the entire delivery. The sample should contain about the same proportion of lump and fine coal as exists in the shipment as a whole. The practice of taking a shovelful near the bottom of the pile should be avoided, as the larger lumps of coal roll down and collect near the bottom and such a sample will not truly represent the coal.

These samples should be immediately deposited in a metal receptacle having a tight-fitting cover and provided with a first-class lock. Except when samples are being deposited or when the contents are being quartered down, this receptacle should be securely locked and the key held by a responsible employee. The receptacle should be placed in a comparatively cool location to avoid loss of moisture in the coal. When it becomes filled, or at the end of the sampling period, the contents should be emptied on a clean, dry floor, in a cone-shaped pile. The larger lumps should be broken down by a coal maul or sledge, and the pile re-formed and quartered into four equal parts, a shovel or board being used to separate the four sections. Two opposite sections should then be rejected and the remaining two again mixed, broken down, and re-formed into a pile to be quartered as before. This process should be continued until the lumps are no larger than pea size, and a quart sample is finally procured. The samples should then immediately be placed in suitable receptacles for shipping and sealed air-tight. The Geological Survey inspectors use a metal can 3 inches in diameter and 9 inches high, with a screw cap 2 inches in diameter, for making shipments to the chemical laboratory. These cans are sealed air-tight by winding adhesive electrical tape around the joint of the screw cap. Each can holds about a quart. or 2 pounds of coal.

The process of quartering down and preparing samples for shipment to the chemical laboratory for analysis should be carried on as rapidly as possible to avoid loss of moisture. The samples should be forwarded promptly and notice of shipment sent under separate cover. Receptacles should be marked plainly on the outside, and a corresponding number or description should be placed inside. A complete record of all deliveries should be kept, showing dates, names of contractor, kind of coal, total weight delivered, condition of coal (wet or dry), and any other particulars of importance.

The procedure at the chemical laboratory of the Geological Survey testing plant is described in Survey Bulletin No. 261. The samples are crushed and ground to a fine powder, and then analyzed and tested.

Persons not experienced in taking samples have a tendency to select a sample better than the average. In many cases a lump of coal is broken and shipped in a cloth sack to the laboratory. This allows the moisture to dry out; moreover, the lump selected is usually free from layers of slate and impurities and of course then represents the best coal in the lot, and shows a higher value than can be expected to hold throughout the coal delivered.

The preceding statements show that the purchaser should usually have the quality determined on the basis of coal "as received," in order to correct any excess or deficiency in the moisture content.

ANALYSES OF COALS DELIVERED TO THE GOVERNMENT.

The following tables, giving the results of tests made by the Geological Survey on coal delivered to the Government Departments, are submitted in response to numerous recent requests for information regarding the quality of coal which may be expected, and the variations in quality which may be found from month to month in coal delivered by the same dealer and presumably from the same mine or group of mines:

Average analyses of anthracite coal delivered to all Government buildings in Washington, D. C., from December 15, 1906, to April 26, 1907.^a

	Furnace.	Egg.	Pea.	Buck-wheat.
Dry coal:				
Volatile matter.....	2.42	3.10	3.02	2.42
Fixed carbon.....	87.14	86.33	80.94	79.53
Ash.....	10.44	10.57	16.04	18.05
	100.00	100.00	100.00	100.00
Sulphur ^b.....	.79	.98	.80	.68
B. t. u.	13,408	13,523	12,487	12,107
Coal as received:				
Moisture.....	4.08	4.16	4.81	5.09
B. t. u.	12,861	12,961	11,886	11,485

^a Payment not based on chemical analysis.

^b Separately determined.

Analyses of anthracite furnace coal delivered during 1907 to a Government building in Washington, D. C.^a

	Jan. 29.	Feb. 2.	Feb. 4.	Feb. 9.	Feb. 11.	Feb. 12.	Feb. 14.	Feb. 15.
Dry coal:								
Volatile matter.....	2.66	2.85	3.32	2.53	3.06	2.56	2.99	2.09
Fixed carbon.....	86.38	86.34	87.66	86.65	85.45	86.69	86.63	86.15
Ash.....	10.96	10.81	9.02	10.82	11.49	10.75	10.38	11.76
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Sulphur ^b.....	.78	.78	.78	.78	.69	.84	.83	.95
B. t. u.	13,297	13,435	13,764	13,418	13,282	13,360	13,427	13,168
Coal as received:								
Moisture.....	4.13	4.19	4.67	4.41	3.83	5.83	4.99	4.33
B. t. u.	12,749	12,874	13,121	12,826	12,773	12,582	12,757	12,595
	Feb. 23.	Feb. 25.	Feb. 26.	Feb. 27.	Feb. 28.	Mar. 13.	Average.	
Dry coal:								
Volatile matter.....	1.56	1.62	2.00	3.34	2.84	2.18	2.51	
Fixed carbon.....	87.96	87.77	88.61	86.12	85.37	87.22	86.74	
Ash.....	10.48	10.61	9.39	10.54	11.79	10.65	10.75	
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	
Sulphur ^b.....	.93	.78	.74	.87	.86	.79	.81	
B. t. u.	13,094	13,346	13,655	13,390	13,166	13,421	13,363	
Coal as received:								
Moisture.....	3.06	3.50	3.99	4.50	5.60	2.12	4.24	
B. t. u.	12,694	12,879	13,118	12,787	12,429	13,136	12,796	

^a Contract for 4,500 tons. Payment not based on chemical analysis.

^b Separately determined.

Analyses of anthracite egg coal delivered during 1907 to a Government building in Washington, D. C.^a

	Jan. 29.	Jan. 31.	Feb. 5.	Feb. 9.	Feb. 11.	Feb. 13.	Feb. 14.	Feb. 15.	Feb. 21.
Dry coal:									
Volatile matter	2.96	2.83	2.57	3.90	3.17	3.53	3.05	3.69	2.86
Fixed carbon	86.29	85.58	86.27	85.39	86.76	86.04	86.90	86.36	85.72
Ash	10.75	11.59	11.16	10.71	10.07	10.43	10.06	9.95	11.42
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Sulphur ^b	.98	.92	.86	1.15	1.06	.98	1.04	1.12	.97
B. t. u.	13,423	13,279	13,836	13,495	13,588	13,614	13,738	13,649	13,328
Coal as received:									
Moisture	4.18	4.34	3.88	4.01	4.11	4.17	4.73	4.51	4.23
B. t. u.	12,863	12,708	12,886	12,953	13,030	13,045	13,688	13,084	12,764

	Feb. 23.	Feb. 25.	Feb. 26.	Feb. 28.	Mar. 3.	Apr. 2.	Apr. 19.	Apr. 24.	Average.
Dry coal:									
Volatile matter	3.60	3.62	3.15	3.22	2.86	3.01	2.89	3.19	3.41
Fixed carbon	87.99	86.00	86.58	86.46	85.53	87.59	86.93	86.36	86.99
Ash	9.40	10.38	10.27	10.32	11.61	9.40	10.18	10.45	9.80
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Sulphur ^b	.94	.98	.99	1.13	1.02	.99	1.08	1.01	.99
B. t. u.	13,798	13,648	13,608	13,617	13,293	13,657	13,672	13,558	13,744
Coal as received:									
Moisture	4.15	3.64	4.07	4.13	3.15	4.08	3.92	4.07	4.15
B. t. u.	13,174	13,291	13,064	13,055	12,874	13,100	13,136	13,006	13,174

^a Contract for 9,000 tons. Payment not based on chemical analysis.^b Separately determined.*Analyses of anthracite pea coal delivered during 1906-7 to a Government building in Washington, D. C.^a*

	Dec. 22.	Jan. 9.	Jan. 24.	Jan. 28.	Jan. 31.	Feb. 5.	Feb. 6.	Feb. 7.	Feb. 11.	Feb. 12.
Dry coal:										
Volatile matter	3.38	2.58	3.73	3.07	3.33	3.39	4.06	3.30	3.77	3.23
Fixed carbon	80.51	84.17	81.84	82.16	80.22	80.80	79.37	80.57	79.95	80.09
Ash	16.11	13.25	14.93	14.77	16.45	15.81	16.57	16.13	16.28	16.68
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Sulphur ^b	.60	.67	.99	1.01	.87	.78	.76	.77	.71	.68
B. t. u.	12,460	12,883	12,877	12,885	12,583	12,623	12,555	12,552	12,418	12,384
Coal as received:										
Moisture	4.35	4.62	5.24	3.40	5.62	5.86	4.27	5.50	6.04	5.78
B. t. u.	11,919	12,286	12,203	12,399	11,876	11,883	12,019	11,862	11,668	11,668

	Feb. 13.	Feb. 14.	Feb. 18.	Feb. 19.	Feb. 25.	Mar. 18.	Apr. 1.	Apr. 8.	Apr. 12.	Average.
Dry coal:										
Volatile matter	2.27	2.32	3.50	3.06	2.13	2.50	2.49	2.51	2.74	3.02
Fixed carbon	82.45	80.45	78.75	81.35	83.24	80.83	79.45	81.00	81.24	80.94
Ash	15.28	17.23	17.75	15.59	14.63	16.67	18.06	16.49	16.02	16.04
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Sulphur ^b	.92	.86	1.05	.89	.68	.80	.69	.64	.77	.80
B. t. u.	12,300	12,317	12,180	12,464	12,627	12,410	12,038	12,284	12,479	12,487
Coal as received:										
Moisture	5.20	4.92	4.58	5.23	5.02	3.85	2.97	5.18	3.77	4.81
B. t. u.	11,660	11,711	11,603	11,812	11,993	11,932	11,680	11,649	12,008	11,886

^a Contract for 6,000 tons. Payment not based on chemical analysis.^b Separately determined.

Analyses of anthracite buckwheat coal delivered during 1906-7 to a Government building in Washington, D. C.^a

	Dec. 18.	Jan. 15.	Jan. 16.	Jan. 22.	Jan. 23.	Jan. 28.	Jan. 31.	Feb. 4.
Dry coal:								
Volatile matter	2.50	1.93	2.21	2.49	2.41	1.98	3.23	2.89
Fixed carbon	80.34	82.40	80.94	80.72	76.32	79.38	78.61	80.57
Ash	17.16	15.67	16.35	16.79	21.27	18.64	18.16	16.54
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Sulphur ^b	.63	.73	.68	.67	.67	.67	.67	.60
B. t. u.	12,245	12,475	12,314	12,370	11,574	11,970	11,843	12,265
Coal as received:								
Moisture	4.70	5.59	4.47	4.93	5.32	4.38	5.13	4.69
B. t. u.	11,659	11,776	11,763	11,755	10,950	11,445	11,236	11,681
	Feb. 7.	Feb. 12.	Feb. 15.	Mar. 2.	Mar. 20.	Apr. 3.	Apr. 13.	Average
Dry coal:								
Volatile matter	1.78	2.66	2.59	2.07	2.87	2.11	2.62	2.42
Fixed carbon	76.91	80.03	79.34	76.90	81.56	79.52	79.36	79.53
Ash	21.31	17.31	18.07	21.03	15.57	18.37	18.02	18.05
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Sulphur ^b	.67	.70	.77	.70	.62	.77	.69	.68
B. t. u.	11,635	12,350	12,098	11,749	12,545	12,109	12,071	12,107
Coal as received:								
Moisture	5.51	5.36	5.57	6.10	4.60	4.31	5.64	5.09
B. t. u.	10,993	11,609	11,016	11,032	11,968	11,587	11,390	11,485

^a Contract for 5,000 tons.

^b Separately determined.

Payment not based on chemical analysis.

Analyses of bituminous coal delivered during 1906-7 to a Government building in Washington, D. C., as being run-of-mine from Georges Creek.

	Dec. 27.	Jan. 3.	Jan. 22.	Jan. 23.	Jan. 30.	Feb. 6.
Dry coal:						
Volatile matter	16.84	16.24	17.26	17.08	16.43	16.66
Fixed carbon	73.01	75.07	75.27	76.23	75.11	75.57
Ash	10.15	8.69	7.47	6.74	8.46	7.77
	100.00	100.00	100.00	100.00	100.00	100.00
Sulphur ^a	1.02	.93	1.08	1.08	.80	.94
B. t. u.	14,017	14,364	14,636	14,764	14,441	14,586
Coal as received:						
Moisture	4.80	2.77	3.43	4.22	3.00	3.73
B. t. u.	13,343	13,966	14,134	14,141	13,995	14,040
	Feb. 9.	Feb. 15.	Mar. 28.	Feb. 21.	Apr. 15.	
Dry coal:						
Volatile matter	16.21	15.77	16.29	16.42	15.76	
Fixed carbon	74.99	75.12	74.55	74.79	76.89	
Ash	8.80	9.11	9.16	8.79	7.35	
	100.00	100.00	100.00	100.00	100.00	
Sulphur ^a	.95	.99	1.08	.95	.95	
B. t. u.	14,317	14,308	14,264	14,352	14,632	
Coal as received:						
Moisture	4.07	3.12	3.15	2.94	2.97	
B. t. u.	13,734	13,862	13,815	13,980	14,197	

^a Separately determined.

SOME PUBLICATIONS ON COAL.

The following are a few of the Survey publications on coal. A more complete list is given in Bulletin No. 316, pages 518-532. The reports here named are now available for distribution. Others are in press and still others are in preparation. Applications for these reports, except for Bulletin No. 261 and Professional Paper No. 48, should be addressed to The Director, United States Geological Survey, Washington, D. C.

Bulletin No. 261. Preliminary report on the operations of the coal-testing plant of the United States Geological Survey at the Louisiana Purchase Exposition, St. Louis, Mo., 1904. E. W. Parker, J. A. Holmes, M. R. Campbell, committee in charge. 1905. 172 pp. Out of stock. Can be obtained by sending 10 cents in cash to the Superintendent of Documents, Washington, D. C.

Professional Paper No. 48. Report on the operations of the coal-testing plant of the United States Geological Survey at the Louisiana Purchase Exposition, St. Louis, Mo., 1904. E. W. Parker, J. A. Holmes, M. R. Campbell, committee in charge. 1906. In three parts. 1492 pp., 13 pls. Out of stock. Can be obtained by sending \$1.50 in cash to the Superintendent of Documents, Washington, D. C.

Bulletin No. 290. Preliminary report on the operations of the fuel-testing plant of the United States Geological Survey at St. Louis, Mo., 1905. By J. A. Holmes. 1906. 240 pp.

Bulletin No. 323. Experimental work conducted in the chemical laboratory of the fuel-testing plant, St. Louis, January 1, 1905, to July 31, 1906. By N. W. Lord. 1907. 49 pp.

Bulletin No. 325. A study of four hundred steaming tests made at the fuel-testing plant, St. Louis, Mo., 1904, 1905, and 1906. By L. P. Breckenridge. 1907. 196 pp.

A few miscellaneous references of special interest may be given, as follows:

Bement, A. The testing of coal. Western Society of Engineers.

Electrical World. Editorial, April 6, 1907.

Engineering Record. Editorial, April 13, 1907.

Parr, S. W. Composition and character of coals. Bulletin No. 3, Illinois Geological Survey, Urbana, Ill.

Preliminary report of committee on coal analysis. Journal of the American Chemical Society, vol. 20, 1898.

Report of the committee on coal analysis. Journal of the American Chemical Society, vol. 21, 1899.

Voorhees, S. S. Analysis of coal. American Society for Testing Materials, 1907.

Woodwell, J. E. The purchase of coal. American Society for Testing Materials, 1907; Mines and Minerals, September, 1907.

CLASSIFICATION OF THE PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY.

[Bulletin No. 339.]

The serial publications of the United States Geological Survey consist of (1) Annual Reports, (2) Monographs, (3) Professional Papers, (4) Bulletins, (5) Mineral Resources, (6) Water-Supply and Irrigation Papers, (7) Topographic Atlas of United States—folios and separate sheets thereof, (8) Geologic Atlas of the United States—folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists can be had on application.

Most of the above publications can be obtained or consulted in the following ways:

1. A limited number are delivered to the Director of the Survey, from whom they can be obtained, free of charge (except classes 2, 7, and 8), on application.

2. A certain number are delivered to Senators and Representatives in Congress for distribution.

3. Other copies are deposited with the Superintendent of Documents, Washington, D. C., from whom they can be had at practically cost.

4. Copies of all Government publications are furnished to the principal public libraries in the large cities throughout the United States, where they can be consulted by those interested.

The Professional Papers, Bulletins, and Water-Supply Papers treat of a variety of subjects, and the total number issued is large. They have therefore been classified into the following series: A, Economic geology; B, Descriptive geology; C, Systematic geology and paleontology; D, Petrography and mineralogy; E, Chemistry and physics; F, Geography; G, Miscellaneous; H, Forestry; I, Irrigation; J, Water storage; K, Pumping water; L, Quality of water; M, General hydrographic investigations; N, Water power; O, Underground waters; P, Hydrographic progress reports, Q, Fuels; R, Structural materials. This paper is the tenth in Series Q, the complete list of which follows (PP=Professional Paper; B=Bulletin):

SERIES Q, FUELS.

B 261. Preliminary report of the operations of the coal-testing plant of the United States Geological Survey at the Louisiana Purchase Exposition, St. Louis, Mo., 1904; E. W. Parker, J. A. Holmes, M. R. Campbell, committee in charge. 1906. 172 pp.

PP 48. Report on the operations of the coal-testing plant of the United States Geological Survey at the Louisiana Purchase Exposition, St. Louis, Mo., 1904; E. W. Parker, J. A. Holmes, M. R. Campbell, committee in charge. 1906. 3 parts. 1,492 pp., 13 pls.

B 290. Preliminary report on the operations of the fuel-testing plant of the United States Geological Survey at St. Louis, Mo., 1905, by J. A. Holmes. 1906. 240 pp.

B 323. Experimental work conducted in the chemical laboratory of the United States fuel-testing plant at St. Louis, Mo., January 1, 1905, to July 31, 1906, by N. W. Lord. 1907. 49 pp.

B 325. A study of four hundred steaming tests made at the fuel-testing plant, St. Louis, Mo., in 1904, 1905, and 1906, by L. P. Breckenridge. 1907. 196 pp.

B 332. Report of the United States fuel-testing plant at St. Louis, Mo., January 1, 1906, to July 1, 1907, Joseph A. Holmes in charge. 1908. — pp.

B 333. Coal-mine accidents: their causes and prevention; a preliminary statistical report, by Clarence Hall and W. O. Snelling, with an introduction by J. A. Holmes. 1907. 21 pp.

B 334. The burning of coal without smoke in boiler plants, a preliminary report, by D. T. Randall. 1908. 26 pp.

B 336. Washing and coking tests of coal and cupola tests of coke, by Richard Moldenke, A. W. Belden, and G. R. Delamater. 1908. — pp.

B 339. The purchase of coal under Government and commercial specifications, on the basis of its heating value, by D. T. Randall. 1908. 27 pp.

Correspondence should be addressed to

THE DIRECTOR,

UNITED STATES GEOLOGICAL SURVEY,

WASHINGTON, D. C.

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